Summary

The aim of this Master Thesis is to analyse the worldwide state-of-the art market solutions and trends in semiconductor sensors within medical applications; specially magnetic and pressure sensors, with the intention of developing a potential entry plan of Infineon Technologies AG into this market. For that purpose, a fit between a top-down and bottom-up qualitative and quantitative estimation of the medical semiconductor sensor's market size has been made; with application units, sensor volumes and sensor revenues, with a horizontal scope of five years. Once understood the existing market, some insight into the competitive landscape is provided, where the key suppliers are analysed in terms of product portfolio and revenue share estimates, on an application basis. And also, a spotlight on innovation and trends at three levels – healthcare, medical devices and medical semiconductor sensors – is presented, to forecast a possible evolution of the fore-mentioned market. The research that has been conducted is based on three main sources of information; internal contacts (i.e. within Infineon), external contacts (most of them through internal references) and internet research. Access to market research company's reports and interviews has been particularly helpful, to complement extensive internet research. Outcomes of this study indicate that the global medical semiconductor magnetic sensor market reveals low revenue potential; as most of the applications are yet innovation fields. Reed switch replacement in battery-powered medical devices can be an opportunity for magnetic switches. However, this project suggests that there is a key investment opportunity: magnetic beads for viral detection with spintronics sensors. The global medical semiconductor pressure sensor market seems a fairly mature market; the gross part of the revenue comes from blood pressure measurement. Blood pressure measurement might be an opportunity for existing automotive semiconductor pressure sensor products. Furthermore, this report suggests that the future of blood pressure measurement might tend towards implantable pressure sensors, with a non-significantly different technological basis. To conclude, this report unveils certain business opportunities for Infineon's semiconductor magnetic and pressure sensor products; and puts special focus on the development of derivative products to pioneer the commercialization of innovative medical applications, with a forecasted huge revenue potential.

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1. Glossary

Ambient Intelligence: in computing, ambient intelligence refers to electronic environments that are sensitive and responsive to the presence of people

AMR: Anisotropic Magneto Resistance

ASIC: Application Specific Integrated Circuit

ASP: Average Selling Price

ATV: Automotive

BAN: Body Area Network

BiCMOS: evolved semiconductor technology that integrates two formerly separate semiconductor technologies; those of the bipolar junction transistor and the CMOS transistor, in a single integrated circuit device

Bionics: is the application of biological methods and systems found in nature to the study and design of engineering systems and modern technology

BLDC: Brushless DC motors

Business Mashups: refers to the integration of business and data services, as business mashups technologies provide the ability to develop new integrated services quickly, to combine internal services with external or personalized information, and to make these services tangible to the business user

CAGR: Compound Annual Growth Rate

CCD: Charged Coupled Device

CCS: Chip Card and Security

CMOS: Complementary Metal Oxide Semiconductor

Coopetition: is a neologism coined to describe cooperative competition

CPAP: Continuous Positive Airway Pressure

CT: Computed Tomography

DBP: Disposable Blood Pressure

DPS: Disposable Pressure Sensors

ECG: Electro Cardiogram

FDA: Food and Drugs Administration

FSL: Freescale

GE: GE Measurement and Control

GMR: Giant Magneto Resistance

GPRS: General Packet Radio Service

GPS: Global Positioning System

Hall Effect: is the production of a voltage difference across an electrical semiconductor, transverse to an electric current in the semiconductor and a magnetic field perpendicular to the current

HAN: Home Area Network

HVAC: Heating Ventilation and Air Conditioning

IC: Integrated Circuit

ICD: Implantable Cardioverter Defibrillator

ICU: Intensive Care Unit

IFX: Infineon Technologies AG

IMM: Industrial and Multi Market

IUP: Intra Uterine Pressure

LAN: Local Area Network

MEAS: Measurement Specialties

MedTech: Medical Technology

MEMS: Micro Electro Mechanical Systems

M-health: Mobile health

MPM: Multi Patient Monitoring

MRI: Magnetic Resonance Imaging

NFC: Near-Field Communication is a set of standards for smartphones and similar devices to establish radio communication with each other by touching them together or bringing them into close proximity, usually no more than a few centimetres

OEM: Original Equipment Manufacturer

PCB: Printed Circuit Board

PET: Positron Emission Tomography

PR: Penetration Rate

RF: Radio Frequency

SoC: System on Chip

Spintronics: also known as magneto electronics, is an emerging technology exploiting both the intrinsic spin of the electron and its associated magnetic moment, in addition to its fundamental electronic charge, in solid-state devices

STM: STMicroelectronics

SU: System Units

Swarm Intelligence: is the collective behaviour of decentralized, self-organized systems, natural or artificial

TAM: Total Available Market

Telehealth: delivery of health-related services and information via telecommunications technologies

Telemedicine: use of telecommunication and information technologies in order to provide clinical health care at a distance (i.e. Telehealth)

TENS: Transcutaneous Electrical Nerve Stimulation

Theranostics: is a proposed process of diagnostic therapy for individual patients to test them for possible reactions to taking a new medication and to tailor a treatment for them based on the test results

TMR: Tunnelling Magneto Resistance

UMTS: Universal Mobile Telecommunications System

WAN: World Area Network

WHO: World Health Organization

WSTS: World Semiconductor Trade Statistics

WW: World Wide

2. Preface

The medical industry (sometimes categorised as part of the industrial sector) for semiconductors is a high growth segment, particularly for semiconductor sensors[1]. Many market research analysts have highlighted for many years the rapid growth of this particular segment of the industry and have spoken about the so-called medical boom. The rationale for an automotive-based semiconductor sensor supplier is simple: today there are round about 80 k cars sold per year[2], whereas there are almost 7000 million people on earth, forecasted to grow up to 9000 million people in 2050[3]. Together with the fact that electronics and, especially semiconductor sensor content within healthcare applications has grown substantially over the last years, triggering the concept of *electronics healthcare*, this, predictably means, that the medical market is a potentially attractive market for semiconductor sensors.

However, there is no clear market research report that quantifies the size of neither this market segment, nor that clearly identifies potential business opportunities for a firm such as IFX, with its current product portfolio and development opportunities. Hence, a better understanding of the medical market for semiconductor sensors is therefore keen to analyse potential business development opportunities for the integrated sensors department of IFX. A thorough increase of knowledge with extensive market research is core to the development of a potential business plan and future market entry evaluations.

It is also worth mentioning that the above-mentioned medical boom is being widely spread throughout other related corporations, which have conventionally served other traditional markets. These firms have made a market transition or expansion, creating and developing new business units to cover the medical segment, demonstrating a clear success in these actions (i.e. Philips Healthcare[4]). There is a growing not yet widespread medical movement at IFX, with ever more research under development and projects such as the so-called *bio screening project*, promoted from the board itself. Within the headquarters, on-going discussion points towards the direction that it is time for IFX to position itself within the medical market, especially in the medical magnetic sensors market; for IFX has the needed technology portfolio, the right products to start and the capability to invest.

3. Introduction

3.1. Objectives of the project

The aim of the project is to obtain a quantitative and qualitative estimation and overview of the medical semiconductor sensor market for magnetic and pressure sensors, with a five years horizontal scope; which includes application units, sensor volumes and sensor revenues.

Furthermore, to understand which the high-revenue medical applications are for both semiconductor sensor types and to identify what is the sensor function and environment, what are the inherent features of the sensor and who are the key benchmark suppliers and customers.

Also, to investigate innovative applications in the medical market for both sensor types that might have a potential impact, in terms of revenue potential.

3.2. Scope of the project

The medical semiconductor sensor market has a wide array of sensor types. This makes it extremely difficult, in terms of scarce resources, to have a complete quantitative picture of the semiconductor sensor market in the medical industry.

Therefore, this project is quantitatively limited to basically two semiconductor sensor types: magnetic and pressure sensors. A spotlight on CMOS image sensors is also given, due to a necessary internal collaboration during the realization of this project within IFX (with the optoelectronics department).

3.3. Methodology

The research conducted has focused on the main following sources of information: reports and interviews from market research companies (i.e. Yole, ISuppli, WSTS, Databeans, SemiCast, TechInsights, Industry experts, Global Industry Analysts, IC Insights), internal experts (i.e. within IFX) and external interviews/contacts (i.e. semiconductor distributors, medical device manufacturers, university professors and medical professionals) together with extensive internet research (i.e. benchmarking medical semiconductor sensor suppliers, medical portals, electronics portals, magazines, articles, datasheets, etc).

4. Budget and environmental impact

4.1. Budget

Up to today, this project has a dedication of ~675h of a junior engineer, and a dedication of ~30h of a senior engineer and a dedication of ~45h of other multiple contributors. Assuming 7,5€/h for a junior engineer at IFX (the project's author), 50€/h for a senior engineer at IFX (the project's tutor), and 35€/h for other contributors, that gives a total amount of ~8150€. Plus, the seven market research reports that have been used and require a licence fee of ~5000€, plus five tear-down reports that have been used with an average price of 1000€ need to be computed. Plus an extra ~100€ spent on conference calls while interviewing different contributors needs to be taken into account.

Therefore, total budget for this project amounts to ~48250 €.

The estimated budget for this project's endeavour will very much depend on the resources available for it and the extent to which it is implemented or not, and hence, any quantification of it is pure speculation and out of today's scope.

4.2. Environmental impact

As for the impact of this project, if IFX decides to move this project forward and implement it when it is consolidated, it is argued that it will be a strategic choice for the company with a high long term revenue potential and, as well, a social influence, for there could be a progressive shift from the traditional markets served (i.e. automotive industry) into the medical market, and the way IFX is perceived as a semiconductor supplier, both internally and externally (adding the healthcare awareness and responsiveness to the company's addressed challenges).

The environmental impact derived from this project's recommendations is self-evident. Being IFX a world leading supplier to the ATV industry, a progressive and gradual shift towards the medical industry will have a global positive effect on the environment. The rationale here is that EV (Electric Vehicles) are prone to be the future of the automobile industry, therefore, chip suppliers into this industry will need to expand other markets in which to sell their products (i.e. the medical market). With a transition into the medical industry, the so-called electronics healthcare is benefiting people's lives, not only in the enhancement of medical devices, but also promoting the transition of vehicle usage into environmentally sustainable vehicles.

5. Infineon Technologies AG

5.1. A brief overview

IFX was founded in 1999, when the semiconductor operations of parent company, Siemens, were spun off to form a separate legal entity. Thereafter, the company based in Munich became a leading innovator in the international semiconductor industry by designing, developing, manufacturing and marketing a broad range of chips and complete system solutions.

IFX has more than 25000 employees worldwide. Within its main customers are Autoliv, Bosch, Continental, Delphi, Denso, Hella, Hyundai, Kostal, Lear, Mitsubishi, TRW and Valeo. And within its main competitors are FSL, NXP, Renesas and STM.

With a global presence, IFX operates through its subsidiaries in the USA from Milpitas California, in the Asia-Pacific region from Singapore, and in Japan from Tokyo. In the 2011 fiscal year (ending September 2011), the company reported sales of 3,997 billion Euro.

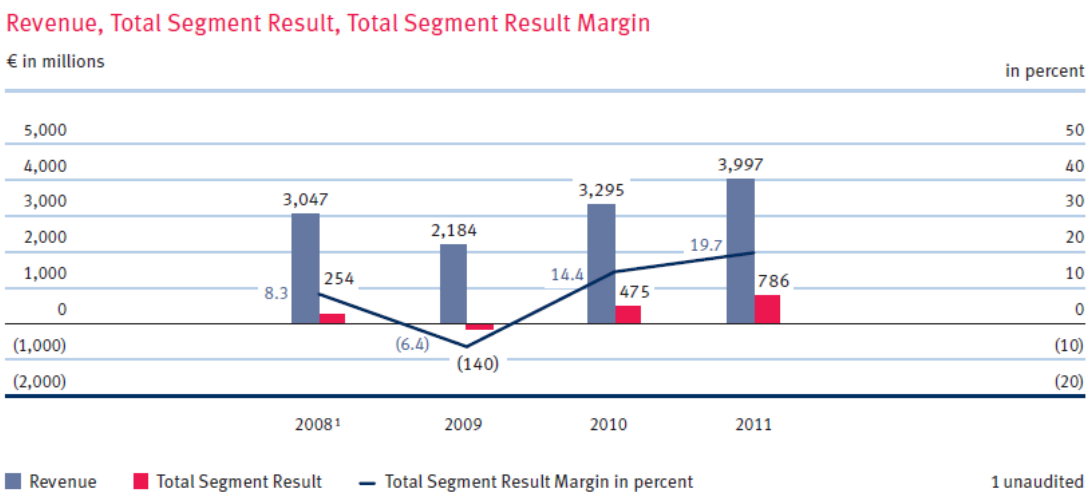

Fig.4.1. *Revenue, total segment result and total segment result margin from 2008 to 2011* (Source: IFX's Annual Report 2011)

IFX focuses on the three central challenges facing modern society: Energy Efficiency, Mobility and Security and offers semiconductors and system solutions for automotive and industrial electronics and chip card and security applications. IFX's products stand out for their reliability, their quality excellence and their innovative and leading-edge technology in analog and mixed signal, RF and power as well as embedded control.

IFX is the world's second largest chip supplier to the automotive industry. IFX's sustained success in automotive electronics is attributed to a consistent focus on automotive applications and their requirements, a profound understanding of the automotive system based on more than 40 years of experience and a broad innovative product portfolio of outstanding quality.

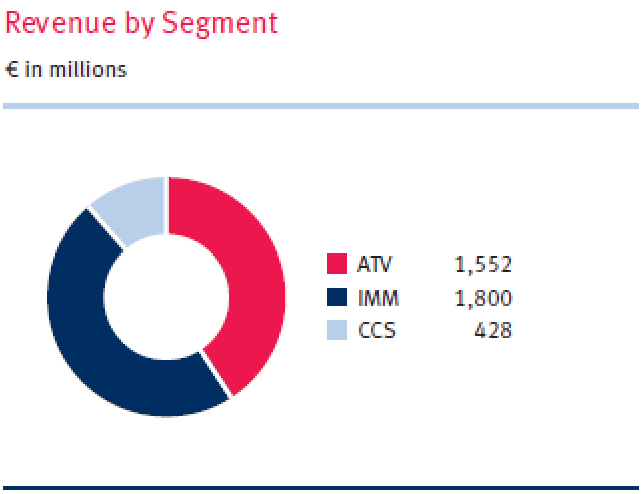

Fig.4.2. *Revenue by segment: ATV, IMM and CCS* (Source: IFX's Annual Report 2011)

The Automotive Division supplies the automotive industry with sensors, microcontrollers, power semiconductors and power modules that contribute to a more sustainable mobility in terms of reduced fuel consumption and emissions, improved safety and affordability[5].

5.2. Relevant product portfolio: semiconductor sensors

The semiconductor's industry is generally regarded as a dynamic and volatile industry (see revenue figures in 2009, for instance). It is a dynamic industry, for there is a constant pressure on chip makers to come up with technologically superior and even cheaper goods. Supporting the technological development aspect, there's Moore's law, which claims that the complexity of ICs (i.e. the number of transistors per chip) is doubling every 24 months. It is a volatile industry, because despite it grows on a yearly basis, its evolution undergoes high fluctuations.

A semiconductor is a substance, usually a solid chemical element or compound, which can conduct electricity under some conditions but not others, making it a good medium for the control of electrical current. Its conductance varies depending on the current or voltage applied to a control electrode[6]. They are the foundation of modern electronics. The specific properties of a semiconductor depend on the impurities, or dopants, added to it. Elemental semiconductors include antimony, arsenic, boron, carbon, germanium, selenium, silicon, sulphur, and tellurium. Silicon is the best-known of these, forming the basis of most ICs. The semiconductor market is divided into two main categories: IC and OSD devices[7]. OSD devices include Optoelectronics, Sensors and actuators and Discretes.

A sensor (also called detector) is a converter (also called transducer) that measures a physical quantity (or parameter) and converts it into a signal which can be read by an observer or by an instrument (today, mostly electronic).

Thus, a semiconductor sensor is essentially a silicon-based electrical transducer. Within this project, we are interested mainly in magnetic and pressure semiconductor sensors.

IFX is a leading sensor supplier in key applications such as Anti-Blocking-Systems, remote keyless entry, the monitoring of side airbags or Tire Pressure Sensors. Worldwide, they supply pressure and magnetic sensors as well as wireless control ICs and radar devices in areas such as safety, powertrain and body electronics. IFX is between the world's leading suppliers of semiconductor-based sensing solutions in the automotive industry, with a total reached number of more than 2 billion units shipped in the last ten years[8].

Constantly increasing requirements for higher accuracy, self-test capabilities and the need for rapid data transmission are fueling the trend towards more intelligent sensors. A growing number of semiconductor sensors feature digital interfaces. Furthermore, they have started taking over functions from the microcontroller, such as pre-processing tasks.

State-of-the-art semiconductor sensors are small, robust and energy-efficient with low power consumption. Typical applications for semiconductor sensors include switches, index counting, position detection, current measurement or pressure measurement.

5.2.1. Magnetic sensors

Magnetic sensors are found to be useful in detecting disturbances and changes in a magnetic field in terms of direction, strength and flux. Several studies are made from the given output, wherein different parameters such as angle, direction, presence and rotation can be easily monitored.

Magnetic Field Sensing

Magnetic sensors convert magnetically encoded information into electrical Signals. Such signals are processed further using electronic circuits for a direct output on the desired parameter.

Conventional sensors and other detectors in general, measure the physical properties of interest. The output of such a measurement is the information that reports directly about the desired parameter. Magnetic sensors also perform the same function, but in an indirect way; they detect changes or disturbances in the magnetic fields and from the information derived from the magnetic fields they measure properties such as presence, direction, electrical currents, angle, rotation, etc.

In case of other detectors, the output reports directly on the desired parameter whereas in magnetic sensors, the output requires further processing to be translated into the desired parameter. The significant advantage derived from using magnetic sensors lies in the fact that they provide reliable and accurate data – with no physical contact.

Magnetic sensors can also be classified on the basis of their sensing field range. In accordance with their sensitivity, magnetic sensors are divided as possessing high, medium or low sensitivity.

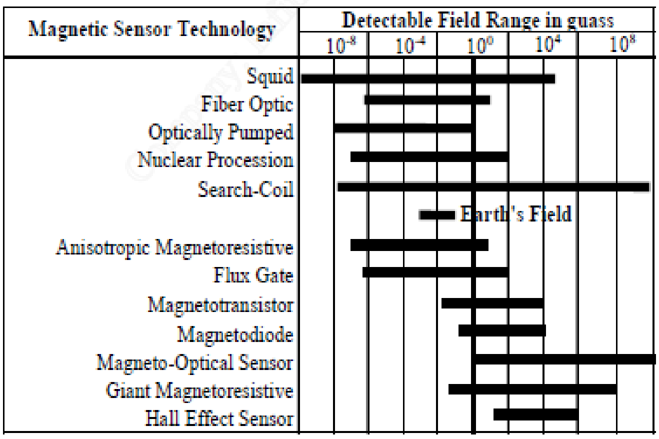

Fig.4.3. *Magnetic sensor technology classified according to the detectable magnetic field range*[9]

Most of the industrial sensors are integrated with permanent magnets, which act as a source of the magnetic field that has to be detected. Such permanent magnets, bias, or magnetize objects made of ferromagnetic metals, that are close to the sensor. The sensor then detects changes occurring in the field around itself. Electrical resistance in metals changes with the application of a magnetic field. Such an effect is known as Magnetoresistance.

Medium-field sensors (Earth Field Sensors)

AMR

AMR Sensors are based on the magnetoresistive effect occurring in ferromagnetic metals. The sensors are capable of measuring angular and linear position as well as the displacement of the magnetic field of the Earth.

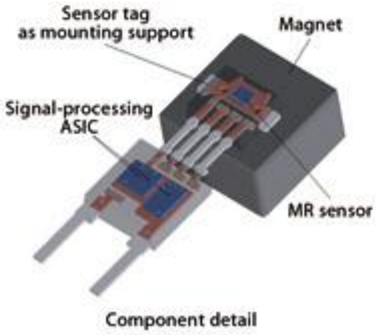

Fig.4.4. *AMR Sensor arquitecture* (Source: NXP)

High-field sensors (Bias Magnetic Field Sensors)

Hall Effect Sensors

Hall Effect Sensors are used as magnetometers for measuring magnetic fields or for inspecting materials by making use of the principle of magnetic flux leakage. A typical Hall Effect Sensor comprises of the Hall Element, which is a thin conductive material sheet, and an integrated circuit chip known as the Hall IC. The Hall element, when in a magnetic field emits an output voltage, which is proportional to the magnetic strength of the field. However, since the output voltage given out by the Hall element is very small, additional electronics are required for achieving useful levels. The Hall IC, the integrated circuit chip makes up for this additional requirement. Major uses of the Hall sensors include consumer, industrial and automotive applications requiring the measurement of position, linear angle, linear position and rotational speed.

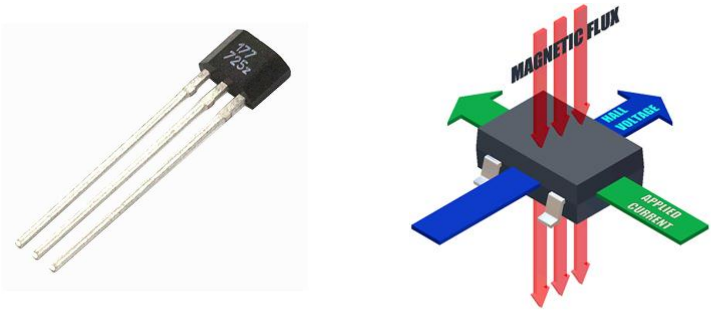

Fig.4.5. *Typical Hall-based magnetic sensor with the Hall Effect operating principle* (Source: ECN Magazine)

<u>GMR Sensors</u>

As opposed to the small change in resistance observed by the mid-field sensing range, GMR Sensors are capable of observing changes in resistances dependent on large magnetic fields. Such changes in resistance are possible in thin non-magnetic layers. The changes in resistance of two ferromagnetic metal layers, which are separated by a thin nonmagnetic layer of conducting material is produced by alteration of the magnetic moments of the ferromagnetic layers from parallel to anti-parallel or by the creation of parallel magnetic moments in the opposite direction. Advantages include: small size, large signal level, high sensitivity, high temperature stability, low power consumption and low cost. They are replacing Hall-based sensors in many market applications.

Applications of GMR sensors include current sensing, rational reference detection, and displacement sensing and proximity detection. GMR sensors are capable of providing position related information by detecting minute displacements occurring in the actuating components of linear position transducers, proximity detectors and in machinery.

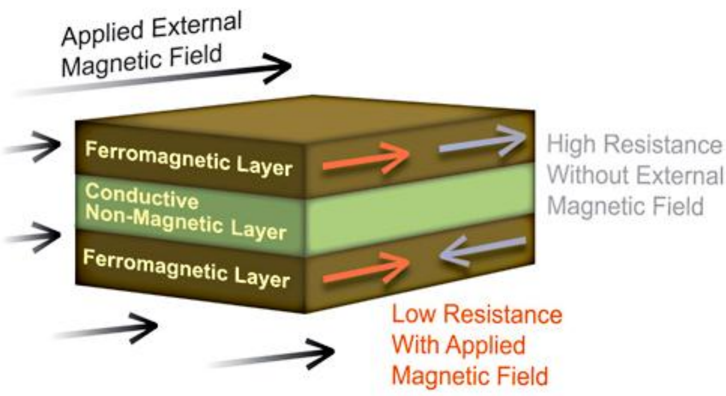

Fig.4.6. *GMR Sensor arquitecture* (Source: Design World)

Reed Switches

A Reed Switch is the simplest of all high-field magnetic sensors. What constitutes a reed switch is a glass container filled with an inert gas and two flexible ferromagnetic contacts, which have been sealed hermetically in it. Reed switches come with the advantages of zero power consumption and of being immune to contamination and dirt. The switches are also maintenance free. It is due to these advantages that these low cost switches are being used in a myriad of applications. However, reed switch replacement is a state-of-the-art trend today.

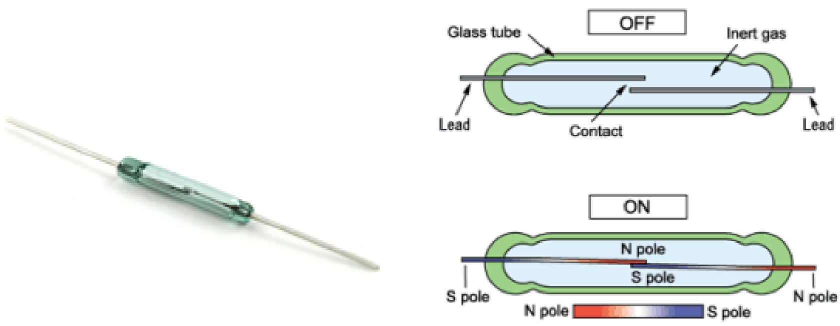

Fig.4.7. *Typical Reed Switch with its internal arquitecture* (Source: OKI)

A new technology is what is known as Tunnel Magnetoresistance (TMR). It is a magnetoresistive effect that occurs in a magnetic tunnel junction (MTJ), which is a component consisting of two ferromagnets separated by a thin insulator. If the insulating layer is thin enough (typically a few nanometres), electrons can tunnel from one ferromagnet into the other. There is a trend in which TMR Sensors are gradually replacing those based on older technologies. Due to their advantageous features of low cost and power consumption, high sensitivity, and small size, the sensors are being increasingly used in a number of sensing applications.

Parameter	**Hall**	**AMR**	**GMR**
Linearity	Linear	Non-linear	Non-linear
Maturity	Very Mature	Mature	New
Integration	Always	Typically	Rarely
Complexity	Simple	Needs one Extra Step	Very Simple
Signal Size	Small	3%	10+%
Sensitivity	Perpendicular	In Plane	In Plane
Offset	Piezoresistive	Low	Low

Fig.4.8. *A comparison of the three main types of magnetic sensing technologies*[10]

IFX's magnetic sensors are used for speed, rotational speed, linear position, linear angle and position measurement in automotive, industrial and consumer applications. Integrated silicon based Hall ICs containing the Hall element and the signal conditioning circuitry monolithically integrated on one single chip is the underlying technology.

Regarding magnetic sensors, IFX has within its magnetics portfolio up to 7 different product families: angle sensors, linear sensors, hall switches, wheel speed sensors, camshaft sensors, crankshaft sensors and transmission sensors (divided into position and speed sensing), covering the whole range of available technologies (AMR, GMR, TMR and Hall).

5.2.2. Pressure sensors

There are several different types of pressure sensors. One is an absolute pressure sensor, which measures absolute pressure using vacuum as a reference point. Another is a gage sensor, which measures pressure by reference to the ambient atmospheric pressure. There are also differential pressure sensors, which measure the pressure difference between two contacts.

Usually, there is an intervening medium between the fluid being measured and the pressure sensor itself. A metallic diaphragm or hermetically sealed fluid chamber is often used. Especially when measuring the pressure of volatile or corrosive materials, an intermediary layer is used to prevent damage to the delicate sensing device.

Semiconductor pressure sensing technologies can be classified into two cutting-edge precision operating principles: piezoresistive and electrostatic capacitance.

<u>Piezoresistive</u>

Mechanical energy can be converted into an electrical impulse with piezoresistive materials. A high-density diffusion layer of piezoresistive material is formed to make a resistive layer on a film. The crystalline form of the piezo material is bent by the compression of this semiconductor film element so as to change its resistance value in proportion to the amount of stress on its surface. The signal changes are then amplified and interpreted as pressure readings. Typically, there are four piezoresistors within the diagram area on the sensor connected to an element bridge.

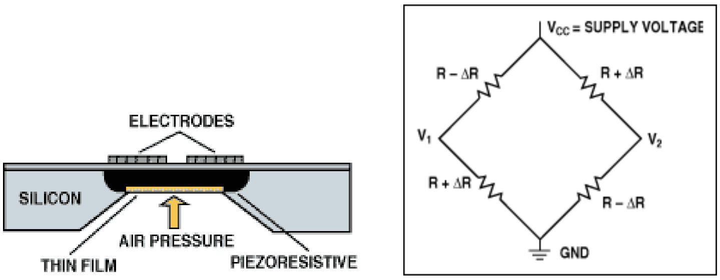

Fig.4.9. *Piezoresistive semiconductor pressure sensor arquitecture* (Source: Sensorsmag)

<u>Electrostatic capacitance</u>

An electrostatic capacitor is formed when two electrodes are separated by a thin dielectric spacer. One electrode is a thin film that has been deposited on a glass substrate where it remains in a fixed position. The other electrode is a movable diaphragm. When a pressure difference between the isolated two pressure ports causes a stress on the movable electrode, the distance between the two electrodes changes, altering the capacitance of the circuit[11]. The signal changes are then amplified by a bridge circuit and interpreted as pressure readings.

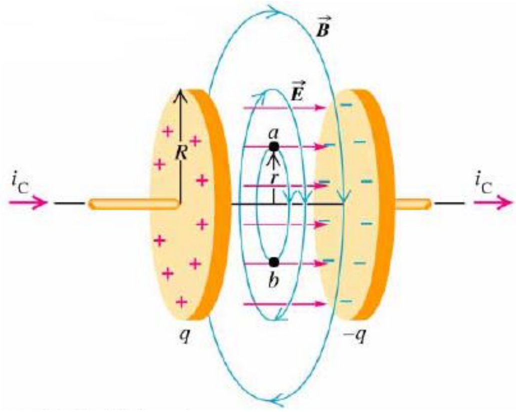

Fig.4.10. *Capacitive semiconductor pressure sensor arquitecture*[38]

IFX's integrated pressure sensor family uses a unique design of multiple surface micro-machined capacitive sensor cell arrays that allows implementing powerful features like the sensor self-diagnoses. The monolithic integration onto one chip allows a state-of-the-art production using a standard automotive qualified BiCMOS process. The combination of sensor cell design with a fully digital signal conditioning and processing with the methods of a high volume standard production flow ensures a superior quality over lifetime.

IFX´s pressure sensors for industrial and consumer use can be used in applications such as altimeters, weather stations, gas meters, blood pressure monitors and many more. IFX's pressure sensors family is available with different pressure ranges and interface options (analog and digital) according to the needs of the individual applications. They can be classified as absolute pressure sensors, where the output signal is proportional to the applied pressure, or relative pressure sensors, where the sensor output is proportional to a change of the applied pressure.

The integration of on-chip temperature compensation and calibration has allowed a significant improvement in the accuracy and temperature stability of the sensor output signal.

Regarding pressure sensors, IFX has within its pressure portfolio up to 3 different product families: Manifold Air Pressure (MAP), Barometric Air Pressure (BAP) and Side Airbag (SAB), all of them covering the low pressure range.

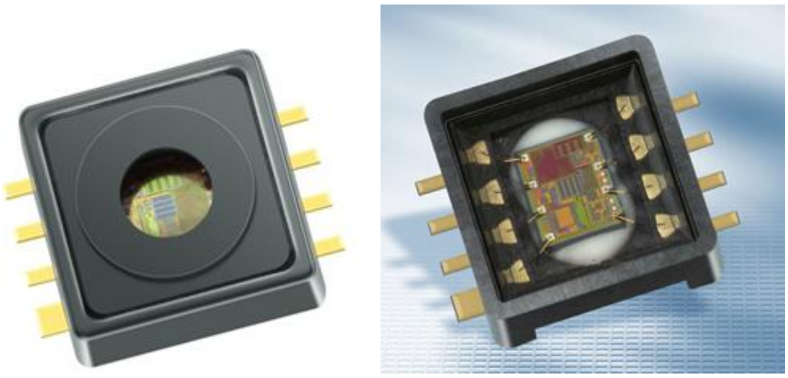

Fig.4.11. *Typical pressure sensor with its internal arquitecture* (Source: IFX)

6. The medical electronics industry: a breakdown into semiconductor sensors

6.1. The medical industry

6.1.1. General trends

In order to be able to dig into the trends that the semiconductor sensors industry is subject to, and to fully understand the environment in which firms that sell to the medical industry operate, it is crucial to breakdown from what are the global trends that the world is currently facing, tackle the healthcare segment in particular and, within that segment, the trends that concern medical devices and applications and, eventually, the semiconductor sensors themselves within those devices and applications.

Today's global megatrends can be summarised in twenty distinguished main drifts[12]. Amongst those, there are some which are more relevant for this project, for directly or indirectly they affect the inherent trends of semiconductor sensors and, therefore, are briefly explained below.

Global trends

Demographic Change

Demographic change is characterized by an aging and declining population in the West, a birth-boom in developing countries, increasing migration flows and by demographic upheavals. Population is estimated to grow up to 9000 million people in 2050.

New Level of Customization

Individualism is a global phenomenon. Personal relationships have been altered: a few strong remain, many are now loose. Market focus has evolved from mass-market to micro-market. The economy has become a "self-sufficient and do-it-yourself" economy.

Booming Health

There's an increasing health awareness and self-responsibility, which is commanded by a health-tech style. New types of food (functional food, gene food, novel food) have aroused and markets are converging (Food – Pharmaceuticals – Medical – Cosmetics).

Digital Life

The nascent Web 2.0 has become a new media conquer in our everyday life. We live in a digital lifestyle; where virtual reality becomes real, even business worlds become virtual. Plus, the emergence of Web 3.0 (with the attributes of: the semantic web, personalization and computer generated information).

Learning from Nature

Biology is becoming the leading science. With the renaissance of bionics and Swarm Intelligence, new forms of social organization are arising.

Ubiquitous Intelligence

There's an on-going Information Technology revolution. Ambient intelligence creates new interfaces and platforms. Neuroscience, artificial intelligence and robotics are on the top, leading towards the transparent society, where monitoring and control is seamless.

Convergence of Technology

Trend towards what is known as NBIC (Nanotechnology, Biotechnology, Information technology and Cognitive Science convergence), paving its way for *iIntelligence*, which is the interaction between information, human behaviour and brain science. Information and nanotechnology are considered to be the key convergence drivers. It is the momentum in many application fields, such as medicine, energy and materials.

Globalization 2.0

There's been a progressive but highly consolidated shift to Asia with a new role of the West. Strategies are becoming ever more global; local and regional strategies must adapt to them, together with the emergence of a global middle class and globalized capital flows.

Knowledge-based Economy

Education and learning are the foundation to a sustainable economy. Innovation is a key driver and competitive advantage, with a new global knowledge-elite or creative group.

Business Ecosystem

Industries, markets and companies face ever more challenges with the consolidation of open systems and networks. There are new value-networks (customer integration and co-opetition) and business mashups (new interfaces generate new markets).

New Consumers

Participation in the prosperity of the third world (bottom of the pyramid) is now a tendency. Luxury consumption is catching up in China, India and Russia. There's a constant seek for sustainable consumption in the West (lifestyle of Health and Sustainability, Eco Chic and Morality Commerce), with a broader spectra of customers (i.e. from kids to seniors).

Sustainable Energy and Resource Usage

Scarcity of strategic resources (fossil fuels, fresh water, minerals, and metals) paves the way for the usage of alternative and renewable energy sources: it is the energy-efficiency revolution, where energy supply tends to be decentralized.

Urbanization

Urban expansion means a strong growth of megacities (metropolitan area with a total population over 10 million people, i.e. Tokyo) which require the development of an appropriate infrastructure and converge in a new residential lifestyle.

New Political World Order

There are two dominant nations with regard to population: China and India, which have to be further taken into consideration. This fact is coupled to the crisis of Western democracies, Russia's renaissance and the awakening of Africa.

Healthcare trends

It is the era of Telemedicine. Healthcare is brought to the patient, in what is known as the point of care delivery of knowledge for decision support. Health is now a round-the-clock service. "Find it and fix it" has paved the way for a "wellness tracking" approach, with a shift from a radar system to GPS logic. Demographics demand it, economics requires it, and technology enables it. The main healthcare trends can be covered with the following arguments:

Increasing aging population

This inevitably leads to the extension of chronic diseases (typically hypertension + diabetes type II) which represent 60% of the deaths worldwide[13]. Hence, escalating levels of supervision and medical intervention are required.

Increasing health awareness and consciousness

With an increasing aging population, healthcare becomes a major concern amongst this segment of the population and, therefore, the perceived value and demand for healthcare increases.

Rising healthcare (hospital) costs and lack of manpower to treat patients

Linked to an increasing aging population and health awareness and consciousness, health care resources are becoming ever scarcer and hospital costs (i.e. the cost of hospitalizations) is increasing.

Need for real-time, reliable and accurate diagnostic results

There's a swelling demand for precise diagnostics on a real-time basis. This induces the need to reduce manual labor and human error with process automation.

Telehealth

Telehealth is also known as Telemedicine or Remote Patient Monitoring. Healthcare has progressively moved from the hospital scene to ambulatory care to, ultimately, home care. In other words, there has been a displacement of area networks, bringing healthcare closer to the individual (from WAN to LAN to HAN to BAN). The last step is BAN or Body Area Networks, where the patient outfits diverse wearable medical devices according to his healthcare needs.

Personalized healthcare

Patient-friendly healthcare (i.e. non-invasive diagnostics and treatment) and tailored healthcare for each patient is ever more common and is driven through meaningful innovation.

Shift in the care-cycle

The care cycle is typically composed of the following stages: prevention, screening, diagnosis, treatment, management and surveillance. Historically, healthcare professionals' methodology was based on cure post-detection. Nowadays, there's the tendency to find and prevent before cure, with an early detection, intervention and management (in a closed healthcare loop).

Patients become customers

With the consumerization of health, patients are ever more important. Efficacy in interoperability and interconnectedness between medical communities and ecosystems is vital, where doctor/patient relationships even become virtual[14].

Emerging markets potential in healthcare expenditures

Long-term potential of emerging markets cannot be underestimated. However, in the short term, healthcare has a lower penetration rate in these markets in comparison to developed countries, due to lack of know-how, expertise and feasible resources to implement innovative solutions.

M-health

Healthcare support through mobile phones and the growing segment of related mobile applications has huge market opportunities[15]. Applications range from simple pill reminders, to complex sensor-based diabetes monitoring applications, for instance[16]. Another example is AT&T's recently added MedApps to its mobile health portfolio.

MedTech as an innovative industrial sector

Upon different sector investments, MedTech is typically under investors' focus. It has, for example, the highest number of technological patent applications on a yearly basis[17].

Medical device trends

Within healthcare, medical devices shipments are on the rise particularly with regards to portable devices[18].

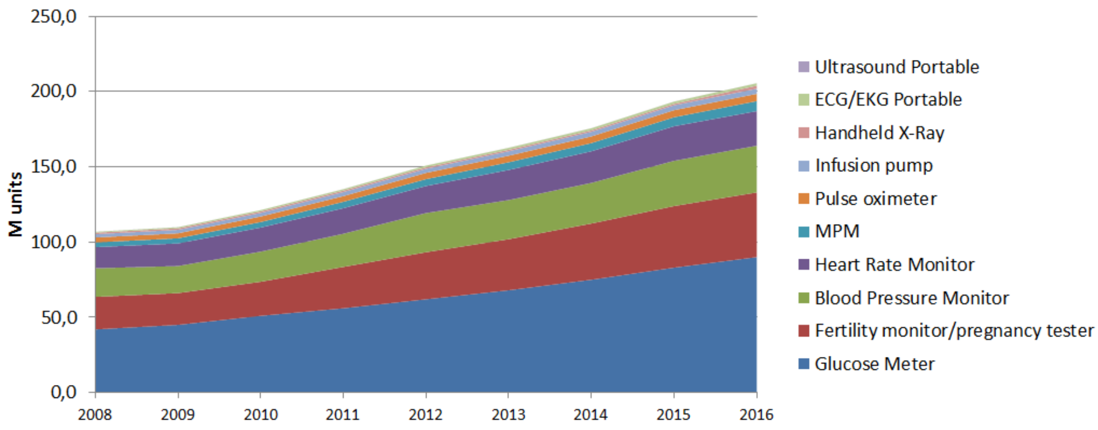

Fig.5.1. *Forecasted volumes for portable medical devices* (Source: Databeans)

Medical devices follow the rule: “Get smarter, stay smaller.” It is the era of smart theranostics; not only users of these devices can expect the device to perform a diagnosis but also to provide with a suitable and individualized appropriate therapy. After thorough analysis and market inspection, these are the foreseeable trends within this segment:

Solution providers

Not only they detect but also they react upon detection, with an improved couple diagnostics/treatment. This feature requires a certain level of integration (i.e. glucose meter with insulin pump reservoir and dispense system at Roche).

Scalability

Scalability is defined as the ability of a system to handle a growing amount of workload. Healthcare professionals are able to reach patients in remote settings and emergency situations (i.e. the ultimate development of ultrasound systems are portable ultrasound devices, which are far ahead from the initial development of ultrasound cart-based devices kept at hospitals for patient treatment). In this sense, medical devices are able to maintain and even increase their level of performance when tested by larger operational demands.

Miniaturization

Migration from static to portable to even implantable devices (i.e. infusion pump from Medtronic) with SoC solutions is an observable fact in many medical application fields.

Power management

Medical devices need to be power efficient, from low to zero power consumption (i.e. implantable devices), with no battery or inductive charging. Dynamic power path management with impedance tracking and battery authentication is typical expected features.

Data security

There’s an on-going concern regarding privacy issues with data treatment. Hence, medical devices must enhance encryption, robustness, liability and safety. Vulnerability of data is yet to be resolved[19].

Connectivity

Telehealth can occur via short range or wireless technologies by remotely connecting the patient to the home security system or the smart phone and to the care giver. For instance, a Bluetooth-enabled medical device (i.e. a blood pressure cuff, a glucose meter or a pulse oximeter) would be connected to an interface (i.e. cell phone, PDA or laptop) via Bluetooth, and through the interface, to the medical portal (i.e. the healthcare professional) via SMS, GPRS or UMTS. So, the measurement of physiological parameters from the patient is remotely controlled by the medical professional in a closed-loop mode.

Sensitivity

Intuitive user interface, touch interface, graphical interface, gesture based recognition are some of the features that are becoming more common in the medical device scenario. Humanization and wearability are being tackled by state-of-the-art innovation projects (i.e. emotional and holistic devices in the Guardian Angels project, for instance).

Smartness

Quality (especially in emerging markets), reliability (devices need to follow a stringent regulatory path, which proves that they are fail-safe; i.e. in the US they are submitted to FDA approval) and technology enhancement with increased functionality (i.e. NFC) are a must in today's medical device development.

To cite an example from many in which to apply the aforementioned trends, one can take a closer look into the evolution of insulin pumps over the last years, for instance. An insulin pump is a medical device that typically delivers medication (insulin to treat diabetes) to a patient intravenously by pushing a syringe or cartridge. In early days, insulin pumps were external devices and static, patients required hospital care (or LAN) to be treated. Later on, portable insulin pumps were developed, so that home or ambulatory care scenarios were available for the patient (HAN). In recent times, this device has become available in the market as an implantable device (a combination of blood glucose sensors with an insulin release system and reservoir), where in a closed-loop mode, the sensor detects the levels of insulin in the patient's body and releases more or less insulin form its reservoir. It is a wearable device (BAN), where sensing (or bio sensing in this case) takes place in an active manner. STM and Debiotech are companies providing this device.

Medical semiconductor sensor trends

Sensors are the key enablers to a better and improved healthcare. They are critical technological components in any electronic system, for they are not replaceable. Partnerships between biochip suppliers, medical companies and hospitals continue to grow. It is the era of pervasive sensing, sensing everywhere. The main trends that undergo this industry segment are the following:

Inherent accuracy

The difference between the indicated output value of the sensor and the actual value (that measured by a primary or good secondary standard) must be rather low, for the sensor must measure parameters as precisely as possible (i.e. integrated pressure sensors with temperature compensation).

Intelligence and capability

Sensors perform diagnostics and are able to test themselves for compliance and functionality. They receive, store, transmit and act upon information (i.e. in a closed loop mode).

Robustness and reliability

Sensors must stick to the zero errors' rule, for in some cases, they must be life supporting devices (i.e. implantable sensors) and, therefore, no errors are allowed under these circumstances.

Small size

Miniaturization is a key enabler for less invasive and painful instruments at lower costs (i.e. nano-sized sensors).

Low power consumption

Striving for self-powered sensors, where energy harvesting may be done in different ways (i.e. utilizing body heat or with the conversion of body movement into mechanical energy and muscle stretching into electricity with nanogenerators or even with the usage of rap music[20]).

Packaging

Archetypally are packaged with surface-mount technology (for smaller footprint on the PCB and ease of manufacture) and lead-less (especially MEMS and nanotechnologies).

Interchangeable functionality

One same variable can be measured in many different ways and with different sensor types.

For instance, there is a trend from using differential pressure sensors to mass-flow sensors in portable respiratory equipment[21]. Another example is that heart rate detection can be done by the pulsatile component of an electric signal, by a bio impedance signal, by an accelerometer signal (using accelerometers as microphones) and by an optical signal.

System-on-chip technology

Facing highly customized ASICs (i.e. for implantable medical devices such as pacemakers and ICDs) with a high degree of integration.

Specialization

There are different sensor technologies depending on the application and function. For there are many types of sensors: disposable, non-disposable, implantable, non-implantable, etc.

Sensor fusion techniques

This characteristic refers to the enhancement of functionality (accuracy of measurements and reliability of interpretations) by the smart combination of sensors for the detection of physiological parameters (i.e. using accelerometer signals to clean other signals by removing motion artifacts in a kind of active-mode noise cancellation system[22]). An illustrative application example is, for example, comparing heart rate with physical activity to know whether the patient has tachycardia when at rest.

Body sensor networks

It is a term coined to describe the interconnectedness between sensors within the human body[23]. It is also referred to as BAN, where sensors are literally wore or outfitted by the patient in a sort of cyborg technology manner.

Market challenges

Stringent requirements arise in terms of regulatory compliance (product safety), with extended product lifecycles (due to long qualification periods and validation trials), a constant pressure to lower prices and a lack of technology awareness amongst medical practitioners.

Taking into account that more than three quarters of the sensor and actuators market's sales come from devices built with MEMS technology[24], why are MEMS sensors so broadly used? There's a variety of reasons, which are in compliance with state-of-the-art trends in this segment, including: low power, silicon interferes less with body tissues, integration permits a large number of systems to be built on a single chip and small size enables less invasive/painful instruments and lower costs, etc.

Some examples might be accelerometers alerting medical professionals when a patient falls and detecting and assessing the severity, signaling for help via GPS providing location information. Or the precise control of the scalpel with pressure sensors sensing the force exerted on the tissues and giving feedback to the surgeon. Or incorporated image sensor in lab-on-a-pill to sample body fluids and pick up patient data such as T, pH, oxygen levels and detect colon cancer. Just to name a few. It is a long time ago since urine analysis involved matching color of a dipped test strip to a chart (now it is automated with optoelectronic sensors).

6.1.2. From medical electronics to medical semiconductor sensors

The medical electronics sector is a complex and fragmented market, with a high growth potential and innovation. Yet, it is always being slowed down by increasing global challenges in regulation, funding and supply chain optimization.

A shift is taking place in the healthcare sector away from a hospital-centric approach towards a more patient-oriented approach, and from a highly centralized model towards a distributed model.

Western Europe and the US have been traditional markets for healthcare expenditures. Besides those markets, today there's a new booming demand which is gradually shifting away from those markets towards the emerging markets, with large and increasingly wealthy populations (especially in India and China). Economic growth in these regions has led to a gradual rise in the quality of medical care that people expect to receive. This is particularly the case in the level of basic medical care.

The ongoing flux of government mandated regulations and a requirement are a factor in the design of medical products and wildly vary from region to region. For example, in China and India, regulations are dictated by regional governments, while in the US products are approved by a very lengthy and difficult FDA approval process known as 501(k). With the increasing complexity of medical devices, manufacturers will need to address the continual changes to regulatory standards and policies that will come in an effort to keep pace with the current and future generations of medical devices.

Tailor-made disease management and health management plans that can help reduce costly and unnecessary medical expenditures are now the emphasis.

Compared to other industries; such as PCs, mobile phones, and consumer electronics, medical electronics must be designed for the long term future, with most medical applications requiring long-life platforms that are available for 10 years or more. System developers therefore must choose components accordingly, bearing in mind that they probably will have to go through a potentially lengthy FDA approval and as many as 10 years of production. As such, the chip suppliers that address this space are taking steps to extend life beyond the basic 10 years that is common in medical life requirements.

The medical market can be further subdivided into three main application segments: the Clinical segment, the Imaging segment and the Home segment[25].

<u>Home segment</u>

The Home medical electronics segment is filled with a myriad of devices that help capture vital parameters and possess multiple connectivity features in order to enable the transport of information between patients and caregivers.

Several factors are influencing the boom in Home healthcare, including an increasingly aging population, rising healthcare costs, and new demand for quality healthcare from emerging markets.

Common application fields for Home healthcare include: general wellness (i.e. digital thermometers, weight scales, pregnancy testers and fertility monitors), fitness equipment, chronic disease management (i.e. glucose meters, heart rate monitors) and remote patient monitoring (blood pressure monitors, electronics pedometers), to name a few.

Remote patient monitoring, in particular, is expected to take off starting in 2011, with the influx of medical monitors that can connect to mobile phones via Bluetooth and other short-range technologies. There are also far more health and wellness smartphone applications becoming available in application stores.

Glucose meters represent the single largest Home application for IC designers, with the highest growth potential. Electrochemical-based glucose meters are the most popular, and are becoming smaller, thinner, and more sophisticated, some of which will soon be able to project glucose levels into the near future. However, glucose monitoring can be done in several different ways, which makes the world of glucose monitoring extremely complex.

Ease of use is a top consideration engineers take when designing medical devices for home consumption. Other worth mentioning features are: intuitive user interface, graphical interface, wireless connectivity (for patient data communication) and power-efficient design (in recent years the use of highly integrated SoC solutions has helped reducing the number of components required in the system, reducing both power consumption and system cost).

Imaging segment

The medical Imaging segment basically consists of high-end low-volume equipment, which is in hospital settings.

Although the healthcare sector in general was among the least affected by the recession, lack of easy credit and lack of financing for new purchases, many hospitals and other potential buyers postponed new equipment purchases. However, the market has fully rebounded post-recession due to technological developments, emerging meaningful applications through innovation.

One recent trend to emerge in the medical imaging industry has been the creation of new corporate venture funds by imaging OEMs, to help them compensate for restricted funding for imaging technologies during the recession. Examples include Philips Healthcare Incubator and Siemens Venture Capital in Healthcare.

Common application fields for the Imaging segment include: ultrasound (carts, portables and peripherals and probes), X-ray (digital and analog), scanners (PET, MRI, CT, Bone Density Scanner) and other imaging (such as dental imaging equipment).

Perhaps the biggest shift occurring within the imaging segment is in ultrasound and CT imaging. These technologies were once limited to cart-based systems, but now accessible imaging from a laptop terminal is becoming far more widespread. Ultrasound technology has been the biggest beneficiary of that integration, with dramatic reductions in both size and cost (i.e. portable ultrasound systems for the diagnoses of strokes, heart disease, abdominal aortic aneurysms, etc. It has even moved from standalone handheld instruments to include the integration of USB-based ultrasound probe technology into smartphones). CT machines have boosted their slice counts up to over 320 slices, which allow obtaining a much clearer and precise scan.

Clinical segment

The medical Clinical segment includes a diverse array of equipment, ranging from simple devices to complex systems.

MPM is the single biggest application. It is a device that monitors and displays multiple physiological parameters from the same patient (i.e. heart and respiratory rates, blood pressure and oxygen saturation levels, and temperature). These devices are continually witnessing improvements in portability, high resolution color displays, and the ability to collect and store a wider array of data types for longer periods of time.

Common application fields for the Clinical segment include: laboratory equipment (scales, microscopes, blood analyzers, etc), drug delivery systems (infusion pumps, dialysis machines), implantable devices (cochlear implants, retinal implants, stent implants, pacemaker implants, defibrillator implants, TENS and neurostimulators implants), monitoring systems (pulse oximeter, spirometer, CPAP, MPM, ECG), other portable devices (venoscope, dermatoscope, nebulizer, handheld X-ray, electronic stethoscope, etc) and other clinical devices (external defibrillator, endoscopes, electronic beds and chairs, ventilators, suction units, incubators, motorized wheelchairs and power scooters, smart pill capsules, etc).

One example in recent years is "smart" infusion pumps, which have become increasingly sophisticated and include features such as close error reduction software, commonly referred to as drug libraries[26]. This technology allows infusion pumps to perform functions to assist healthcare providers with programming and calculating dose and delivery rates, and in turn, help prevent intravenous medication errors and reduce patient harm.

Medical electronics

Global medical electronics market is ~155 billion USD in 2011 and will grow with a $CAGR_{11\text{-}16}$ of 12% up to a TAM of ~243 billion USD in 2016. The major medical electronics OEMs include Siemens Healthcare, GE Healthcare, Medtronic, Philips Healthcare and Johnson & Johnson.

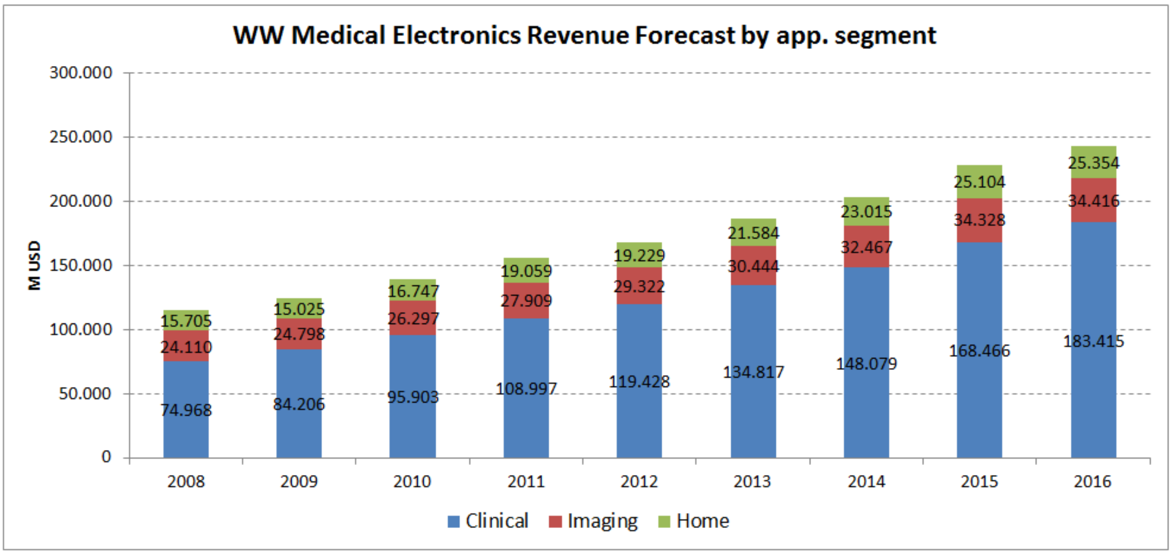

Fig.5.2. *Worldwide Medical Electronics revenue forecast by application segment* (Source: Databeans)

Medical semiconductors

Global medical semiconductor market is ~4 billion USD in 2011 and will grow with a $CAGR_{11\text{-}16}$ of 10% up to a TAM of ~6,6 billion USD in 2016.

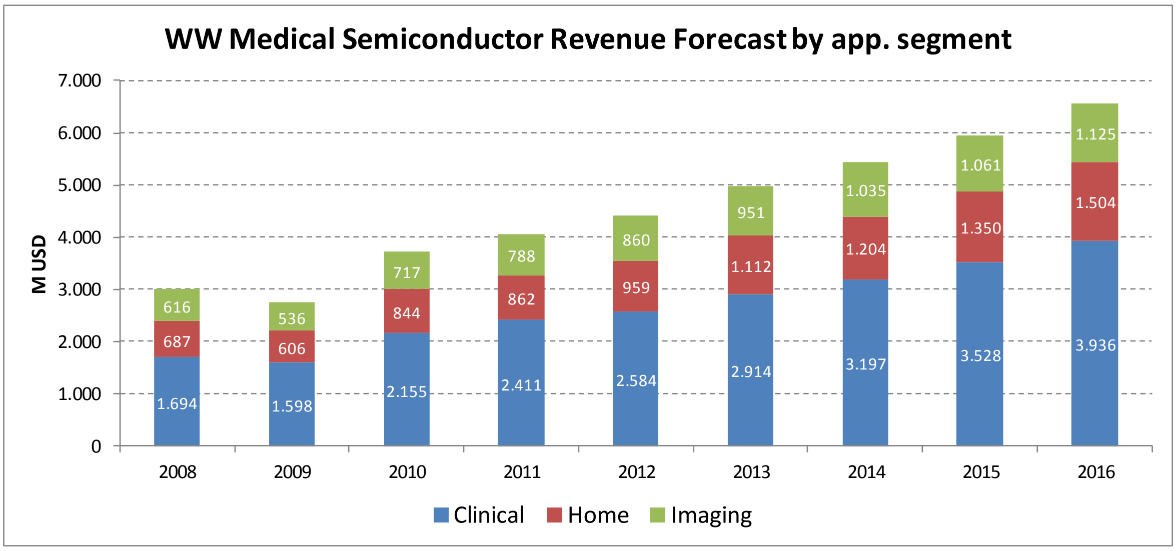

Fig.5.3. *Worldwide Medical Semiconductor revenue forecast by application segment* (Source: Databeans)

The medical semiconductor market will remain the second smallest industrial semiconductor market but with the highest $CAGR_{11\text{-}16}$ (10%) due to a global aging population and an increasing healthcare awareness and demand.

The Clinical sector will continue to dominate the market with an overall 60% (TAM will reach ~4 billion USD in 2016 with a $CAGR_{11\text{-}16}$ of 10%).

The Home sector will grow 12% annually on average (23% worldwide in 2016). The Imaging sector will grow 10% annually on average (17% worldwide in 2016).

A shipment-based application segment split would reveal that the Home sector accounts for ~80% worldwide (~232 M Units) and the Clinical sector for ~20% worldwide (~55 M Units) in 2011. Imaging is mostly composed of high-end products with very low volumes. Total medical semiconductor shipments will reach ~410 M Units in 2016 ($CAGR_{11\text{-}16}$ of 7%).

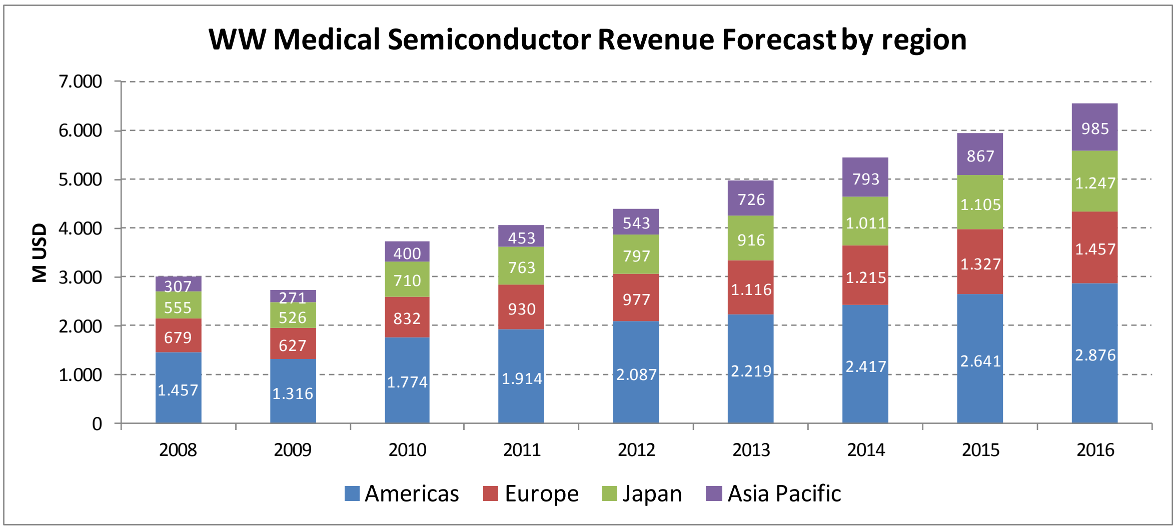

Fig.5.4. *Worldwide Medical Semiconductor revenue forecast by application segment* (Source: Databeans)

The Asia Pacific market is expected to grow at a $CAGR_{11\text{-}16}$ of 17% and would account for 11% (15%) of the global market in 2011 (2016).

The Americas market is expected to grow at a $CAGR_{11\text{-}16}$ of 8% (44% of the worldwide market in 2016), The Europe market by 9% (23% worldwide) and Japan´s market by 10% (19% worldwide).

A shipment-based regional split would reveal a surprising picture: Asia Pacific will out-grow (at a 28,5% $CAGR_{11\text{-}16}$) and reach the Americas share (with a 30% in 2016). Developing Asia Pacific regions are becoming market leaders in smaller, faster and more affordable medical devices.

Medical semiconductor sensors

Recall that global medical semiconductor market is ~4 billion USD in 2011 and will grow with a $CAGR_{11\text{-}16}$ of 10% up to a TAM of ~6,6 billion USD in 2016.

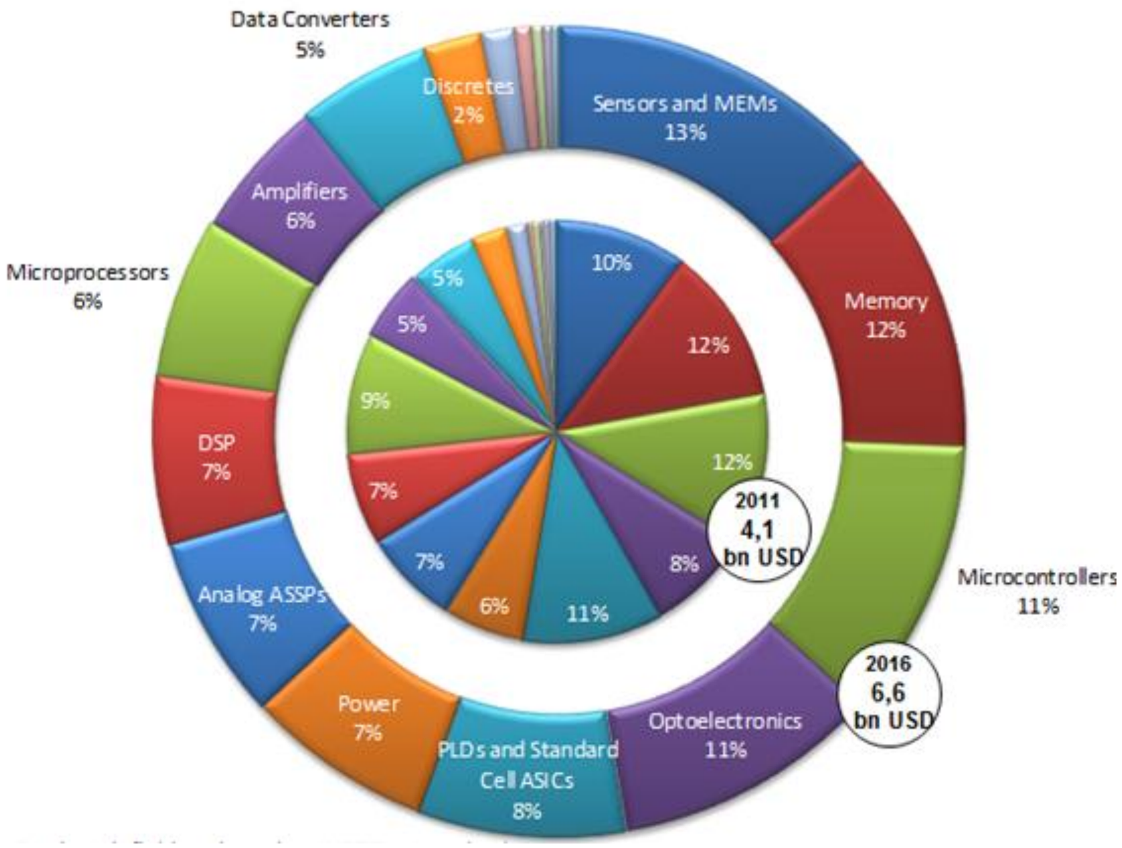

Fig.5.5. *Worldwide Medical Semiconductor Revenue split by product type in 2011 & 2016* (Source: Databeans)

Note1: Product definitions are based on WSTS categorization.

Note2: Sensors and MEMS include temperature, pressure, magnetic field, yaw rate sensors and other MEMS (microphones, micro fluidic devices and optical MEMS). It also includes actuators (piezoelectric, micro mirrors and saw filters/other resonators). Special purpose sensors are not included unless manufactured by a semiconductor sensor supplier.

Note3: Optoelectronics includes LED´s, displays, couplers, opto-switches, laser pick-ups and transmission, infrared and image sensors.

Sensors & MEMS will become the biggest product type in 2016 (13%, 877 M USD) with the highest $CAGR_{11\text{-}16}$ (~16%). Market drivers are twofold[27]: strong growth in remote patient monitoring and the boom in implants and catheters along with mature market with externally used sensors (some applications are disposable, which drives unit volumes); also sensor networks (outfitting of patients with wireless sensors).

Optoelectronics will remain the fourth largest semiconductor category in 2016 with the second largest $CAGR_{11\text{-}16}$ (16%, 687 M USD).

A shipment-based portrait would reveal the highest $CAGR_{11\text{-}16}$ for Optoelectronics (25%, 6 billion units in 2016) and Sensors & MEMS (22%, 1,2 billion units in 2016).

The top 7 medical semiconductor suppliers include STMicroelectronics, Infineon, Texas instruments, Analog devices, Renesas, Toshiba and NXP.

6.2. Worldwide medical semiconductor sensors

If we take a deeper look into the medical semiconductor sensor market, and we attempt to categorize by sensor type, the picture that we obtain reveals a highly diversified market and, therefore, the necessity to focus on the relevant sensor types, in this project magnetic and pressure sensors (and a spotlight on CMOS Image Sensors).

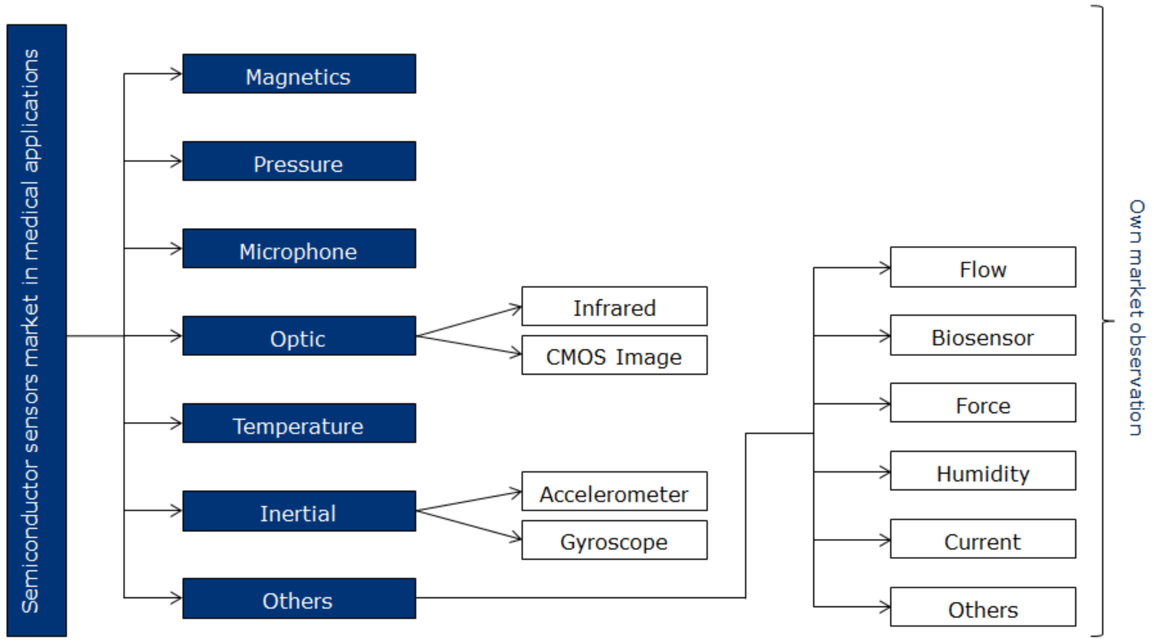

Fig.5.6. *Worldwide categorization of medical semiconductor sensors by sensor type* (Source: own market inspection)

The above classification has been made based on own market observation, by investigating different medical semiconductor sensor suppliers, medical device manufacturers, sensor magazines, electronic portals and articles, tear-down reports and market reports. Please note that biosensors, in general, are not considered semiconductor sensors. However, some may contain semiconductor sensor content as one of the integrated parts of the sensor. Others include special purpose sensors that may contain semiconductor content.

It is also possible to adopt a different perspective when analyzing the global medical semiconductor sensor market, and that is, a categorization according to the nature of placement of the sensors. This classification reveals different technological opportunities and challenges.

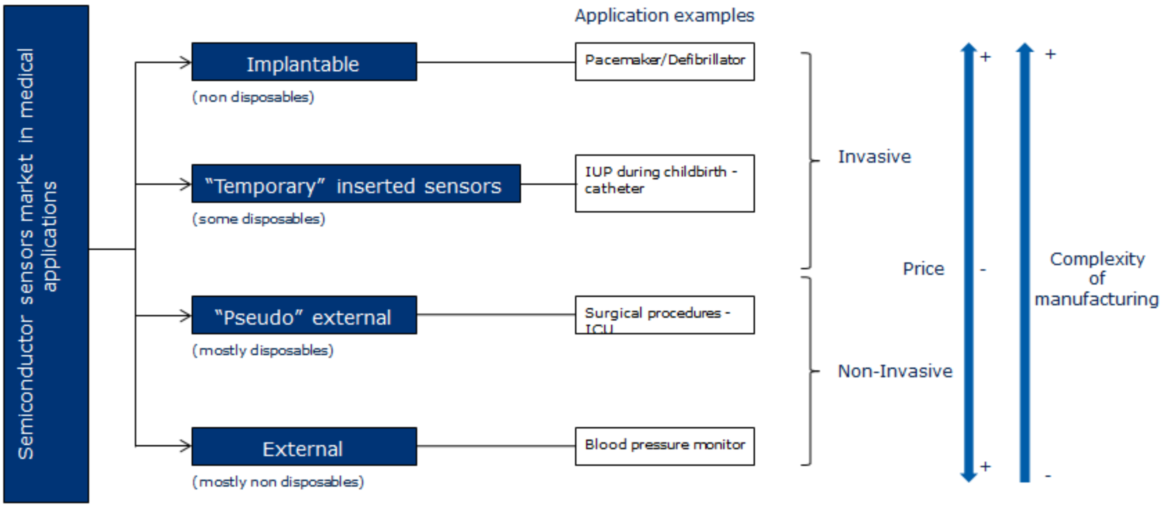

Fig.5.7. *Worldwide categorization of medical semiconductor sensors by nature of placement*

The above taxonomy is based on extensive market research and by adoption of a benchmarking supplier's explanation on the usage of different sensor types[28].

Thus, sensors can be either invasive (contact with the human body) or non-invasive (no contact with the human body) and disposable (one time use) or non-disposable (more than one time use). The couple invasive/non-invasive with disposable/non-disposable mainly depends on where that sensor is placed within the human body or its environment.

A brief description of each category is presented below:

- Implantable: implantable sensors are small, lightweight, and compatible with body mass and require very little power to function. They cannot decay over time. They must be submitted to FDA approval (for they are used in class III medical devices[29]). In average, entail 2/4 years for development and implementation. Are typically more expensive and require a specialist to surgically implant them.

- "Temporary" inserted sensors: require FDA approval, as well. They generally last from a few minutes to a couple of hours of functioning time. Ideally they do not require external power to operate. They are inserted through incision, in body cavities (typical catheter-type applications such as IUP).

- “Pseudo” external: the sensor stays outside the body but body fluids come into contact with it. One example is DPS, considered to be the ideal way to measure blood pressure when intravenous fluids are administered to the patient. Must be replaced every 24 h to maintain hygiene, as a rule of thumb.

- External: neither medication nor body fluids come into contact with the sensors. Mostly are non-disposables. Typically they are used in hospital or home care applications. Examples include CPAP, infusion pumps, spirometers, oxygen conservators and blood pressure cuffs.

If we dig into the medical magnetic and pressure semiconductor sensors market, we can see that it is an apparently low-growing market (4% $CAGR_{11\text{-}16}$) that will achieve a ~232 M USD TAM in 2016. It is necessary, though, to analyse them separately, in order to understand the inherent characteristics of each market.

6.2.1. Methodology

Ideally, the core outcome of a thorough market research would be able to provide a consistent market model from which all results could be derived. However, it is not always possible, in terms of knowledge-base and resources, to achieve the so desired robust model. Therefore, hypothesis and guesses with a certain expertise must be made and, in a sort of puzzle construction framework, a pseudo robust model can be completed in order to make reasonable market prognosis.

This so-called market model, which is developed in an excel basis, consists of a series of inputs which, linked together, provide certain outputs. It is generally known as bottom-up TAM estimation.

The market model segmentation consists of up to four different breakdowns: industry, segment, application field and application. And, therefore, each medical application (up to 120 applications listed) is clustered within its application field (up to 20 application fields listed), within each segment (up to 3 segments listed) and of course within the medical industry. For instance, a glucose meter pertains to the chronic disease management field which is in turn within the Home segment in the medical industry.

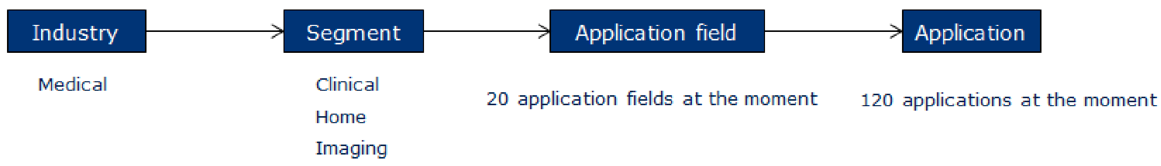

Fig.5.8. *Market model segmentation* (Source: own Market Model)

Once the clustering of the different medical applications within the medical industry is done, a semiconductor sensor screening for each application must be executed, in order to grasp knowledge on which type of semiconductor sensor might that application contain, what function does than sensor develop and what device type does that application require (i.e. if an application contains a magnetic sensor, should it require a position sensor or a speed sensor, or if an application contains a pressure sensor, should it measure barometric pressure or manifold pressure). An example can be a newly developed electronic toothbrush by Braun that contains a pressure sensor, where the function of this sensor is to trigger an alarm if the brushing pressure is exceeded.

Knowing which application contains which semiconductor sensor, a series of inputs needs to be computed, and those are: system units (SU), penetration rates (PR) and average selling prices (ASP), with a horizontal time frame of up to 5 years (2011-2016, for availability of data purposes). SU are the number of each medical application sold on a yearly basis. Penetration rates are the average number of sensors per application for a particular sensor type (it aims to estimate the share between different technological solutions available for one particular application). Average selling prices are the average price at which one sensor type is sold in a particular application. Thus, if we calculate SU x PR we obtain sensor volumes and, if we calculate now sensor volumes x ASP we obtain sensor revenues, for each particular application for each of its sensor types. Therefore, with SU, PR and ASP as inputs, we can obtain sensor volumes and sensor revenues as outputs.

The focus, of course, has to go for the higher revenue applications first (and it is not always easy to know which ones are those), as they will generate the bulk part of the total revenue. Then, minor niche applications may be incorporated to the model, to have a more precise understanding of the market.

For example, in 2011, an amount of 192000 k units of electronic toothbrushes were sold. Electronic toothbrushes may contain pressure sensors. Assuming that the PR for 2011 was of 0,1 (in an electronic toothbrush, the average number of pressure sensors is 0,1 or, to put it in other words, 10% of all electronic toothbrushes sold in 2011 contained a pressure sensor and this number reflects the different technological solutions in the market, for not all electronic toothbrushes, of course, contain this additional feature), 19200 k units of pressure sensors were sold in 2011. Assuming that the ASP for these pressure sensors is 0,25 USD in 2011, the total revenue made from pressure sensors in electronic toothbrushes was of 4,8 M USD.

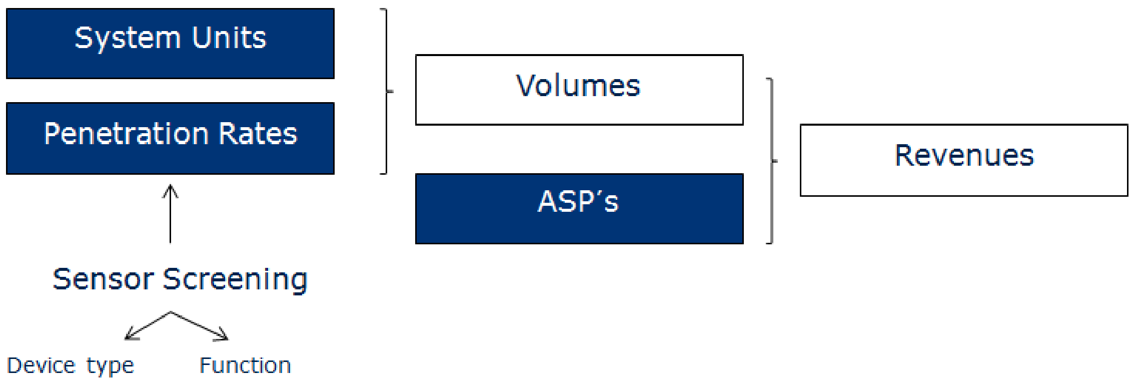

Fig.5.9. *Market Model build-up*

Hence, once this model is completed (and under the assumption that it is also complete and actually reflects the reality of the market), by adding up all different sensor revenues for all applications within a sensor type, you can obtain a fairly accurate estimation of that particular sensor's market size. Plus, as it is done on an application basis, one can get an idea of which applications are the most interesting to target, if so, from a revenue viewpoint.

However, please note that this particular market model, for its nature, doesn't include potential innovative medical applications that might have a huge sensor revenue potential in a more of a longer term perspective. It is a picture (dynamic picture, if any) in a short to mid-term perspective of the market and, therefore, reflects what the current market looks like and will probably look like in the forthcoming five years.

Now, once the methodology is clear, it should be also clear that acquiring all those inputs with a high degree of accuracy is far from being feasible. Common hurdles encountered for the different inputs are listed below:

- SU: it is not always possible to find good SU estimates, for some applications are rare or are used in integrated systems (i.e. in ICU, anaesthesia machines, ventilators and infusion pumps can be integrated into the same medical device and therefore obtaining the SU for each application separately is not obvious).

- Function and device type: due to a knowledge lack, it is not easy and simple to understand the sensor environment.

- PR: different suppliers might use different number of sensors and for different purposes within the same application, for within electronics, there is no one single solution to a problem and one function can be performed interchangeably with different sensor types (i.e. pressure and flow measurement, as noted before) and in different ways. Knowing which suppliers dominate the market, to estimate the share of each technological solution, is not evident.

- ASP: here similar issues arise as for PR, for every supplier prices their sensors at different levels (depending on quantity as well, plus premium discounts) and, in general, pricing information is not unveiled for the public.

Amongst the resources used to fulfil this methodology are mainly extensive internet research (benchmarking different top suppliers), market analyst reports and interviews with discussions and follow-ups, application tear-down reports, expert know-how, etc. Some reverse engineering was attempted but discarded due to the expensiveness of many medical applications. And, even if one had on hand a medical device to apply some reverse engineering to it, one would only find PR for one particular year and for one particular technological solution; whether that number is representative or not of the benchmark in the market, that is something that has to be submitted to expert consensus.

Another perspective on the market is what is known as a top-down TAM estimation, which attempts to size the market from a global perspective, without considering an application basis. It is typically done by market analyst companies by aggregating the main supplier's data and using macroeconomic and trend factors for forecasts. Sometimes it is even done by difference (for example, one may black box the sensor content of a system and if the rest of the system data is known, by difference, obtain the sensor data).

Ideally, there would be a perfect fit between a top-down and bottom-up market estimation, regardless of which of the two methods is used, the TAM for a particular market should be the same. However, this is not always the case and what is normally done is a puzzle between both methods, for some information comes from one of the methods and some other information will be found on the other method. Plus, certain hypothesis and assumptions, where needed.

So, for instance, one may know the total number of pressure sensors that the company GE sold in the year 2011 for blood pressure monitor, with their ASP, and also what is the number of blood pressure monitors sold in the year 2011. In this case, in order to know what is the total revenue generated by pressure sensors within blood pressure monitors; one could assume that GE, being a benchmark supplier for that application, sold those sensors at the markets ASP (and therefore, GE’s pricing level is representative of that of the market) and that the penetration rate of the market is similar to the one seen in GE’s technological solution.

Regarding the competitive landscape, to have a better understanding of the market, an attempt has been made to analyse how the competitive landscape is from a top-down perspective. That means, who are the different medical semiconductor sensor suppliers, what is their product portfolio and what share do they have for each sensor type. The degree of accuracy, however, is drilled down to: who are the key suppliers for magnetic and pressure sensors and if they are benchmark suppliers (i.e. market leaders) or not, and if they address specific medical applications or application fields. Market shares are pretty much stable over time and, therefore, if nothing exceptional happens, market shares in 2011 will be more or less preserved till 2016.

Documentation of sources, hypothesis and assumptions is highly important in such a model, for continuum purposes (extension of the knowledge-base), for a market model such as the one described here is continually updated with the most recent figures (inputs) and expertise, typically on a yearly basis, and tries to adapt to reflect as accurately as possible the realistic market picture.

Application selection is crucial. For, as mentioned above, high-revenue applications will account for most of the revenue and, therefore, the majority of the effort in constructing such a model should attempt to go for them. So, how can one know beforehand (i.e. before conducting such a research and gaining some know-how on the industry) which applications to choose to strive for their SU, PR and ASP’s?

The answer is not simple. And it is probably an iterative process in which some applications are selected on some criterion basis but while researching, some new data is found which alters the previous selection and requests the need for a new selection.

One initial option to serve as criteria for the application selection is to create a scatter plot of the market size in 2016 of the sensor & MEMS content of the applications from a benchmark market report[30] (i.e. provided the applications contain the relevant sensor types, for within the sensor & MEMS category there are many other semiconductor sensor types that might be of no interest), versus the $CAGR_{11-16}$ for all listed applications (i.e. where applicable) and, from there, select the stars (i.e. the ones that have a highest market size and $CAGR_{11-16}$, which corresponds to the upper right part of the graph presented below).

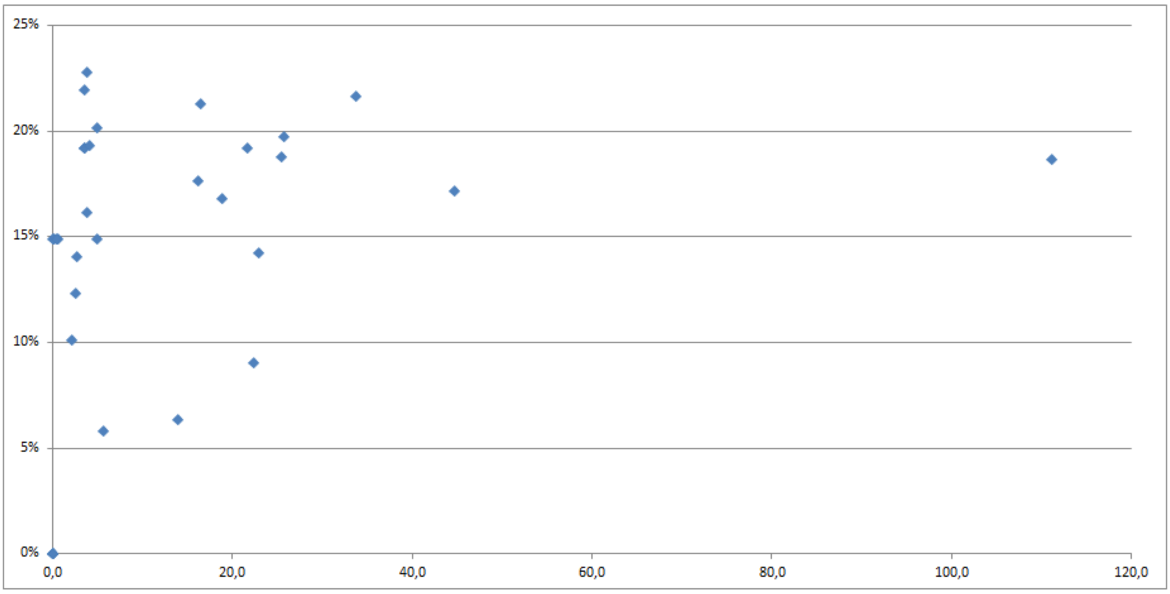

Fig.5.10. *Scatter plot of $CAGR_{11-16}$ (Y axis) versus market size for sensor & MEMS content in M USD (X axis) for different medical applications* (Source: Databeans)

How to proceed

This project is thought to be a starting point, if IFX were to decide entering the medical market. In order to fulfil the basis for a potential business plan, a more comprehensive analysis regarding the competitive landscape and IFX's position should be made (as well as extending the knowledge base regarding the market with updated figures and expertise). So, the logical stages for this project's continuum and extension might be: market research, competitive analysis, IFX's position and business case.

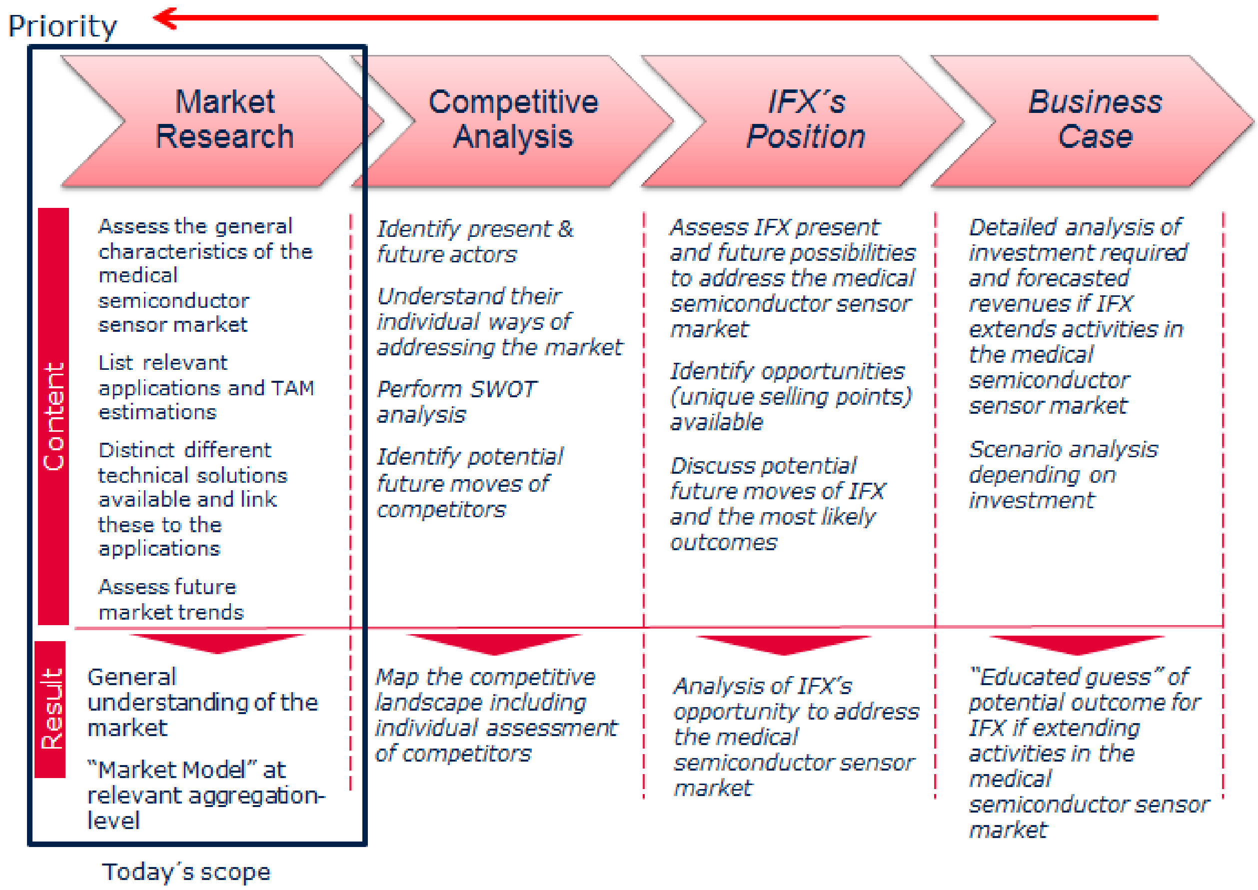

Fig.5.11. *Proposed stages for this project's continuum*

Therefore, some ideas and guidelines are given, regarding today's scope of the project, so as to move forward.

Concerning the so-called market model, a more insightful application-based analysis of PR and ASP should be made. Upon its closure, a check should be made with the top-down market perspective. To proceed, check Digikey, Farnell and others (electronic components distributors) for ASPs at an application level (some semiconductor sensor suppliers such as Honeywell specify which particular sensor they use at an application level). Consider buying further market reports (Freedonia group, Frost & Sullivan, Nexus, etc).

Regarding the competitive landscape, a more detailed competitor assessment and revenue breakdown could be made, by analysing competitor´s product portfolio and applications served and derive a strategy positioning for each relevant competitor (in magnetics: NVE and Honeywell; in pressure: GE, Honeywell, MEAS and FSL).

As regards the top-down TAM estimations, other sources for inputs should be searched for in order to contrast the actual numbers.

For the trends and innovation part, a further investigation of innovative companies and research centres might be useful. Magnetic beads for viral detection (i.e. NVE) and implantable blood pressure sensors (i.e. CardioMEMS) are ‘hot’ topics and companies to keep track of. The research centre at Dräger is also prone to further study.

Another option worth considering is developing a knowledge base for the relevant application portraits, so that in one clear slide, one can know everything regarding that specific application (i.e. blood pressure and respiratory devices for pressure; hearing aid, implants and medical pill for magnetics). To accomplish that purpose, consider buying specialized books to understand sensor usage in medical applications (i.e. *Medical Instrumentation Application and Design* by John Webster, *Biomedical Sensors and Instruments* by Tatsuo Tagawa, Toshiyo Tamura, P. Ake Oberg and *Sensors in medicine and healthcare* by P. Ake Oberg, Tatsuo Togawa, Francis A. Spelman.

However, in order to do it properly, expert contact (people who have long been working in the medical industry with sensors and applications) is for sure required.

6.2.2. Magnetic sensors

The global medical semiconductor magnetic sensor market will achieve a TAM of 31 M USD in 2016, with a $CAGR_{11\text{-}16}$ of roughly 2%. ASP in 2011 is ~1,4 USD, with a compound annual decrease rate of ~3%. It is a small and slow growing market, with low revenue potential.

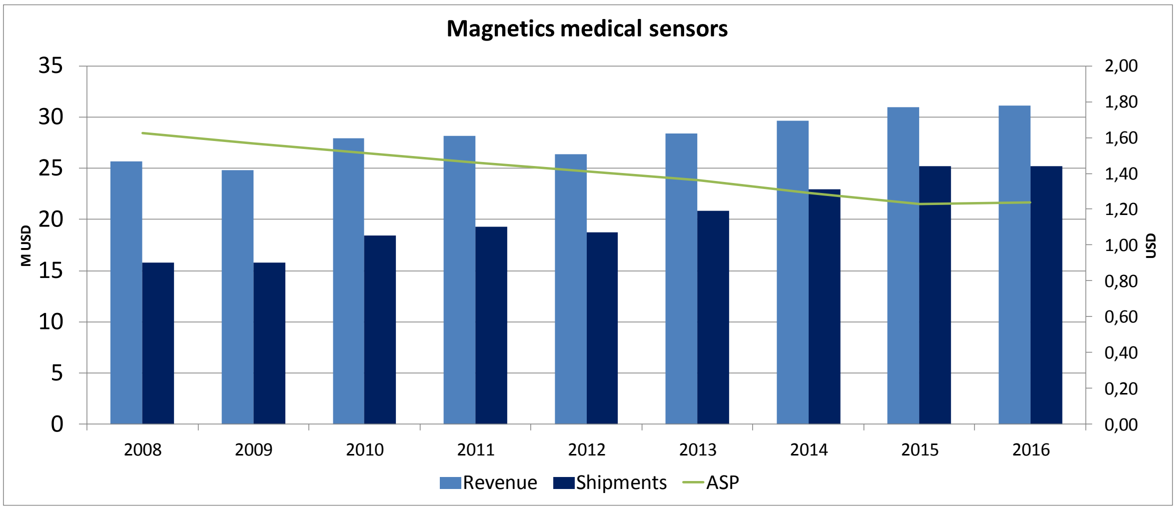

Fig.5.12. *Worldwide medical semiconductor magnetic sensors market: Revenue, Shipments, ASP* (Source: ISuppli)

Market and competitor analysis

Applying the described methodology, a comprehensive analysis of the results is provided as follows.

Regarding the competitive landscape, data which is available is the total revenue made for sensors and actuators for some companies in 2010 and 2011 (from which one can derive growth rates) and the total revenue for magnetic sensors from 2011 to 2016 (TAM). Therefore, an assumption that must be made to obtain quantitative data is the % of sensor revenue spent on medical for different companies, which is their market presence, etc.

Additional data from market inspection is that NVE Corporation is pioneering high-end products and, thus, is particularly strong in hearing aid and implants (especially pacemaker and defibrillator implants) and that Honeywell is particularly strong in cross-selling of products from other mass market applications and other innovation fields (i.e. automation of laboratory equipment and medication dispensing cabinets, for instance).

Key magnetics players
NVE corporation
Honeywell (Sensing&Control)
Measurement Specialties (MEAS)
Melexis
NXP
Allegro microsystems
Sensitec
Austria microsystems

Fig.5.13. *Key medical magnetic semiconductor sensor suppliers by sensor type with a high (dark blue) or low (light blue) degree of certainty* (Source: own market inspection)

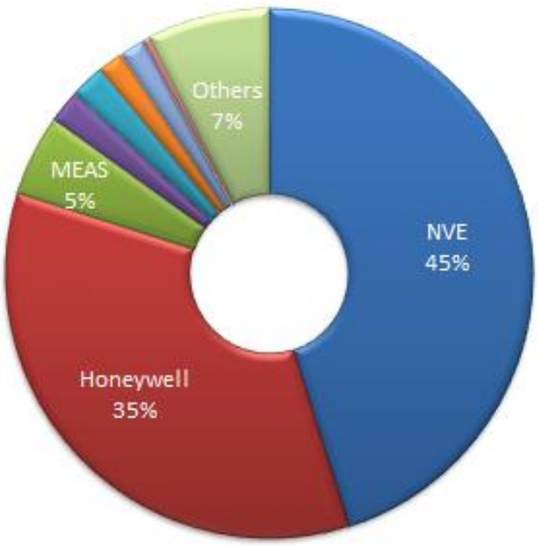

Fig.5.14. *Medical magnetics semiconductor sensor supplier's revenue shares estimation in 2011* (Source: own Competitor Model)

Regarding an application-based portrait of the market, this is how it looks like:

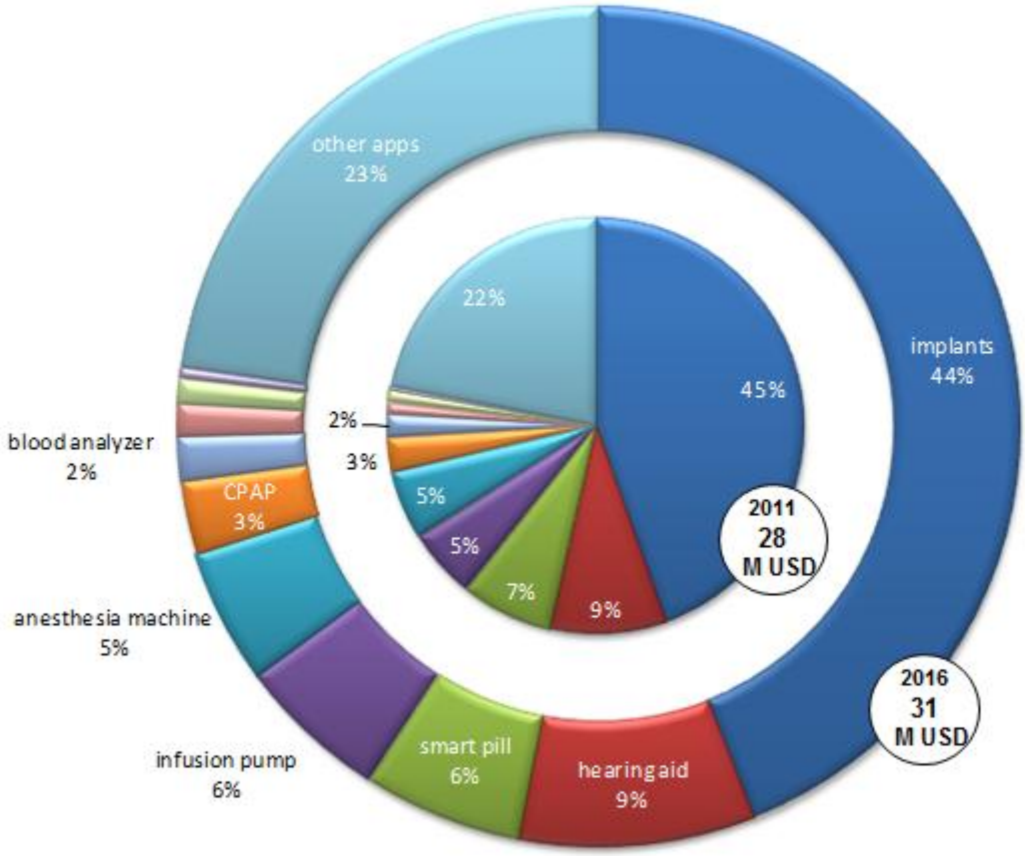

Fig.5.15. *Worldwide medical magnetic sensor revenue split estimation by application in 2011 & 2016* (Source: own Market Model)

The magnetic sensors market is expected to grow at a 2% $CAGR_{11-16}$ and reach 31 M USD in 2016. Most of the application fields are innovative applications.

Implants (ICD´s, pacemakers, TENS & neurostimulators), hearing aid (& cochlear implants) and smart pills will account for 60% of the total market in 2016 (~19 M USD).

Other applications include the cross-selling of magnetic sensors from other mass markets (for example, BLDC for motor control in infusion pumps, dialysis machines, CPAP, ventilators, anesthesia delivery machines and powered scooters). Speed sensing is used in fitness equipment and position sensing is used in medical beds and chairs, dental fixtures and surgical tables/carts.

Other innovative applications include: automation of laboratory equipment such as liquid handling systems (electronic pipettes, blood analyzers and automated coding of chariots), medical dispensing cabinets and control knobs on equipment and prosthesis/rehabilitation equipment.

Other innovative application fields that are not reflected in today's market picture, might be the usage of Hall-based or GMR-based sensors for viral detection (i.e. magnetic beads), reed switch replacement in glucose meters and body motion reconstruction technology systems.

Typical device types include magnetic switches. Typical technologies include Hall but also GMR. Main targeted function is reed switch replacement.

A complete list of medical devices currently using semiconductor magnetic sensors are: fitness equipment, glucose meters, MRI scanners, magnetocardiography devices, dental imaging equipment, blood analyzers, automated laboratory equipment, infusion pumps, dialysis machines, hearing aids, cochlear implants, pacemaker implants, defibrillator implants, TENS and neurostimulators implants, CPAP, powered scooters, electronic beds and chairs, ventilators, surgical tables and carts, prosthesis, surgical robots, anesthesia machines, smart pill capsules, blood recovery systems, medication dispensing cabinets, electronic pipettes, control knobs on equipment, etc.

High-revenue applications

The medical semiconductor magnetics market is dominated by a fairly small number of applications which are proper medical applications: hearing aid (cochlear implant), pacemaker and defibrillator implant and smart pill capsule. No single application is expected to vary significantly its revenue market share in the upcoming years. The headline should read: "reed switch replacement in battery-powered medical devices: an opportunity for magnetic switches."

<u>Hearing aid and cochlear implants</u>

Hearing aid and cochlear implants are used to amplify and modulate sound for the hearing impaired (typically in, behind or out of the ear arquitecture).

Magnetic switches used in hearing aid and cochlear implants together they account for a rough 9% of the total magnetics market, in terms of revenue (~2,4 M USD in 2011).

Key supplier is US-based NVE Corporation (i.e. NVE Corporation put an order of 0,1 M USD in 2004 for Starkey Labs, one of the world's leading innovative manufacturers of hearing aid applications[31]). However, NVE's devices require an average 5 years period for FDA approval. Other relevant potential sensor customers are Siemens & Phonak (which together account for a rough 60% of the market share).

It is an early phase innovation field[32]. For most technological digital solutions incorporate reed switches today, but also GMR (1-1,5 USD) competes with Hall (0,5-0,75 USD), due to its very low noise floor and its precise switching at a given field strength. TMR is potentially being offered at NVE. MEMS switches are offered for higher-end devices (for instance, at Asulab).

The potential use of magnetic switches here is reed switch replacement. Their main function is to perform automatic switching in signal processing modes. It enables hearing aids to switch modes for various sound sources without user´s intervention (i.e. when a cell phone approaches the wearer's ear).

Fig.5.16. *Typical behind the ear hearing aid device* (Source: Portable Medicals)

<u>Pacemaker and defibrillator implants</u>

Pacemaker implants are used to maintain a suitable heart rate, whereas defibrillator implants are used to prevent from a cardiac arrest.

Magnetic switches used in pacemaker and defibrillator implants account for a rough 45% of the total magnetics market, in terms of revenue, they are the biggest application (~12,5 M USD in 2011).

Again, key supplier is NVE Corporation (i.e. they were placed an order of 0,2 M USD in 2001 to 1,2 M USD in 2003 solely for pacemakers by St. Jude hospital[33]). Its devices, as well, require an average of 5 years for FDA approval. Another potential customer is Medtronic.

An overview of NVE's typical device features can be seen below:

Company	**Device type**	**Tech**	**Operating point**	**Supply voltage**	**Package type**	**Power**
NVE	Magnetic switch	GMR	1,5 mT	0,9-2,4 V	4 pin ULLGA, 1,1 x 1,1 x 0,4 mm	29 nW at 0,9 V

Fig.5.17. *NVE's GMR-based sensor technology overview* (Source: NVE)

Today, the generalized technology used is reed switches, but also GMR (2-5 USD) is competing with Hall.

The potential use of magnetic switches here is again reed switch replacement. When the switch is closed, it paces the heart at a continuous pre-set rate (pacemaker) or prevents it from delivering treatment therapies (defibrillator). When the switch is open, normal programming applies. Other functionalities might as well include checking the battery status, for instance.

Other potential implants included in this category are: TENS and neurostimulators and infusion pumps (here magnetic switches can be used as a medication level sensor).

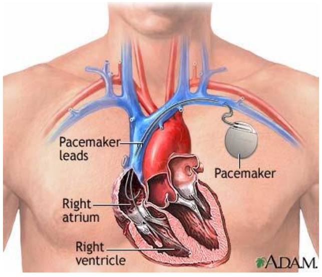

Fig.5.18. *Typical pacemaker device* (Stanford Medicine)

Smart pill capsule

A smart pill capsule is a battery-operated wireless device that with camera videos its descent into the stomach and through the small intestine as it is swallowed; enhancing traditional gastro intestinal endoscopy techniques.

Magnetic switches here account for up to 6% of the magnetics revenue (~2 M USD in 2011).

Main supplier is company MEMSCAP, who is providing benchmark pill manufacturers such as Given Imaging and Smart Pill Corporation.

Most are reed switches today and MEMS switches, but also Hall switches (3-5 USD) are starting to be offered at the market place.

The opportunity here is once again reed switch replacement. The magnetic switch is used to activate the battery triggering the camera of the pill.

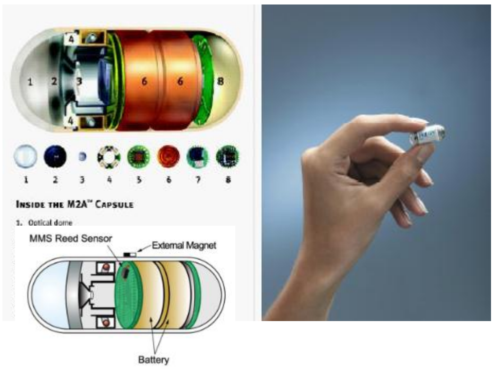

Fig.5.19. *Typical smart pill capsule* (Source: ISuppli)

A spotlight on innovative applications

There are other application fields that are using and might be using magnetic sensors. However, these are basically niche market applications to be further analyzed, which are not included, in general, in the existing application-based market picture, for their revenue potential is unknown or estimated for a longer term perspective.

<u>Automated coding of chariots</u>

Automated coding of chariots is an identified new application field within liquid handling systems. The function of the magnetic switches would be that of coding experiments. Technical features required are: small size, low or no power consumption and contact-less. Technological choices include reed, Hall and GMR. Up to 7 Hall switches may be needed[34].

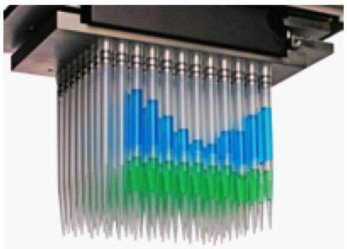

Fig.5.20. *Automated coding of chariots* (Source: ISuppli)

<u>Electronic pipettes</u>

Magnetic switches in electronic pipettes may be used for a precise control of the dosage. Precise pipetting typically requires the dropping of very small amounts of reagents (of the order of nanolitres). Therefore, magnetic switches would be substituting mechanical switches (the incumbent technology) for reliability reasons. One Hall switch would be needed[35].

Fig.5.21. *Electronic pipette* (Source: Eppendorf Corporation)

Blood analyzer

A blood analyzer typically has rotating blood probes from which samples are extracted. Automation requires magnetic sensors for position-sensing of the extraction needle and the blood probe holder. Up to 4 Hall switches may be used in this application. Honeywell claims this potential usage.

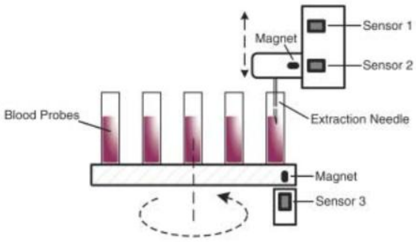

Fig.5.22. *Blood analyzer scheme* (Source: Honeywell)

Medication dispensing cabinets

Here the function of the magnetic switches is to enable remote locking and unlocking of medication dispensing cabinet drawers. Honeywell claims this potential usage.

Fig.5.23. *Medication dispensing cabinets* (Source: Pharmaceuticals Partners of Canada)

Prosthesis and Rehabilitation

The analyst firm ISuppli (part of IHS now) claims that magnetic encoders are used in prosthetic joints, by firms such as MEAS-HL Planar (i.e. prosthetic knee). The function of the magnetic sensor is not clear, though. Another potential use might be in rehabilitation equipment.

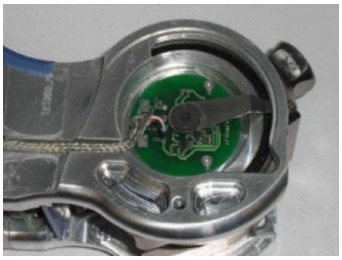

Fig.5.24. *Prosthetic knee* (Source: ISuppli)

Body motion reconstruction technology

Body motion reconstruction technology is used for effortless orientation estimation in embedded applications in firms like STMicroelectronics (the so called iNEMO system). It applies the measurements to a graphical skeleton model and displays body motions in real time. It may be used for clinical and sports medicine applications. The function of the magnetic sensor is not clear, though.

Fig.5.25. *Body motion reconstruction technology* (Source: STMicroelectronics)

Glucose meter

Reed switches are being used at Meder Electronics for calibration and mode changes in glucose meter related applications. The sensor is implanted in the waist area and is used in conjunction with an insulin reservoir and a dispense system. Therefore, it might be another opportunity for reed switch replacement.

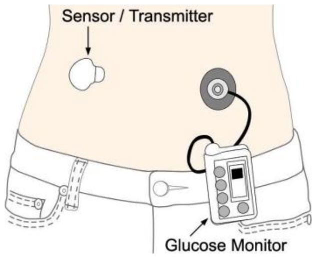

Fig.5.26. *Glucose meter system* (Source: Meder Electronics)

The company also claims usage of these devices, for instance, to detect clogged carotid arteries, and, therefore, this application might be another possible opportunity in which Hall or GMR based magnetic switches are used and substitute reed switch technology[36].

However, if there is a star opportunity for magnetic sensors, this is magnetic beads for viral detection. The idea behind is that of speeding up the diagnosis for medical conditions with spintronics sensors. Low-cost disease diagnostic tools are amongst the biggest opportunities foreseen by market research companies[37]. For instance, imagine that influenza could be easily detected with a low-cost magnetic sensor-based medical device. Or even further, that exotic viruses like malaria could be identified with the same device, on remote settings. Revenue potential is paramount.

The idea is that first, a drop of blood is placed in a micron-scale well on the chip. There, it mixes with tiny micron-scale magnetic beads that are pre-coated with an antibody that bonds to the antigen indicative of a particular disease. If the antigens are in the blood sample, the beads grab onto them. Then, gravity causes the beads to fall onto a tiny array of magnetic sensors at the bottom of the well. The sensor array (can be Hall-based or GMR-based) is also coated with the particular antibody that binds to the disease antigen. After the beads settle, a magnetic field is applied. Beads that aren't now immobilized by the antigen on the surface of the chip are pulled away from the sensor array (it is called a magnetic washing).

Finally, the sensor array is activated. The electrical resistance of the array corresponds to the number of beads that are stuck on the sensors thanks to the antibody-antigen bond. The detection of immobilized beads means the particular antigen is present and that the subject whose blood was tested most likely is infected with the analyzed virus (the entire process takes little more than a minute when this methodology is applied to test patients for the dengue virus, for instance). Furthermore, one could imagine buckets of these chips, all coated with different antibodies so that not only one can detect on-the-spot when someone is ill, but also find out exactly what illness they have[38].

The following illustration depicts how antigens bind to both the magnetic beads and the magnetic, here Hall-based, sensors on the surface of the chip.

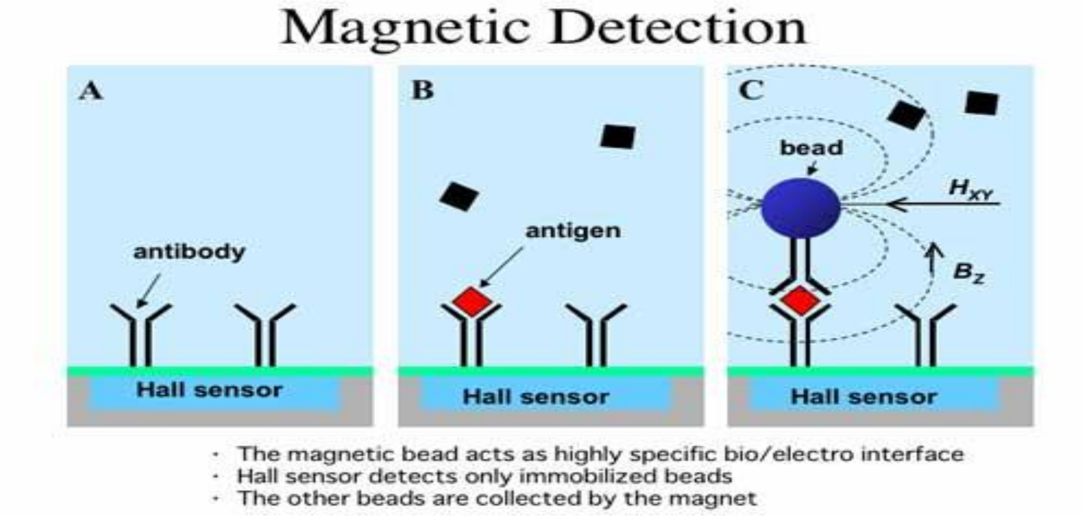

Fig.5.27. *Operating principle for magnetic beads in viral detection applications* (Source: Berkeley)

A more comprehensive functional scheme of the process is presented below:

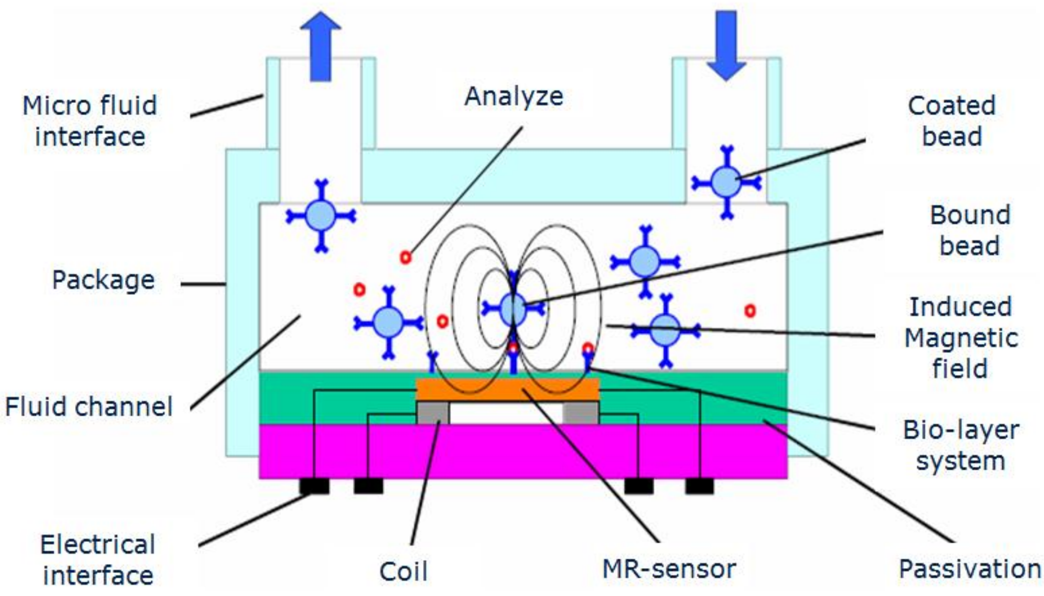

Fig.5.28. *Functional scheme for magnetic beads in viral detection applications* (Source: IFX)

There are many research centers and companies who are conducting research and development in this field of interest, which motivates the importance of it. A rally can be observed regarding who will pioneer its commercialization:

- NVE Corporation: tiny magnetic beads that serve as biological markers in proposed lab-on-chip systems. Nano-beads adhere to an immobilization surface when a targeted biological agent is present, and can be detected by spintronics biosensors. 3 patents since 2004.

- Philips Magnotech system: uses the magnetic beads principle to test for damage to a heart (testing for troponin, which is the protein that dead heart cells release into the bloodstream). Instead of magnetic detection, Philips opts for optical detection, striving for lower unit costs.

- Life Technologies Corporation: magnetic bead-based viral RNA isolation from diverse biological samples (already commercially available at a very high price).

- Brown University Research: A SMART(er) way to track influenza (06/2012).

- UC Berkeley: ImmunoSensor chip. The chips are donated by National Semiconductor and then modified in UC Berkeley's Microfabrication Laboratory, <1 USD each, tests for Dengue virus.

- Scientific Papers: “An integrated microfluidic system for diagnosis and multiple sub typing of influenza virus”, “Detection of respiratory viruses by multicode ® PLX using barcoded magnetic beads.”

- Other companies in this research field include: STM, IBM and Dräger.

6.2.3. Pressure sensors

The global medical semiconductor pressure sensors market will achieve a TAM of 201 M USD in 2016, with a $CAGR_{11\text{-}16}$ of roughly 4%. ASP in 2011 is ~1,8 USD, and will remain stable over the next five years. It has a higher order of magnitude revenue potential than the magnetics market, and a slightly higher growth rate.

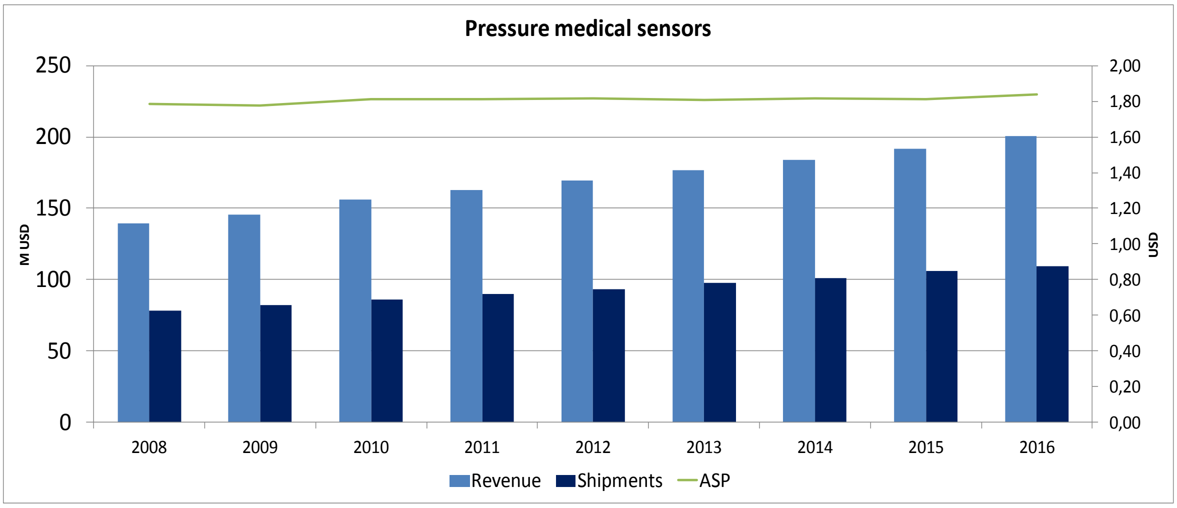

Fig.5.29. *Worldwide medical semiconductor pressure sensors market* (Source: Yole)

Please note that first level package (i.e. die-level components) are considered for pressure sensors (as for liquid environments, stainless steel sheath usage would increase cost structure tenfold).

Regarding the supply chain mechanisms, it is a highly diversified market with a lot of small players; it is hard to know who integrates the pressure die (second level packaging). However, regarding first level packaging, GE, MEAS, Honeywell and FSL are the main semiconductor pressure sensor manufacturers (typically, they may purchase silicon pressure dies from MEAS and resell them). Low volumes are sold through distribution whereas large accounts are handled directly with medical device manufacturers.

Market and competitor analysis

Applying the described methodology, a comprehensive analysis of the results is provided as follows.

Regarding the competitive landscape, data which is available is the total revenue made for sensors and actuators for some companies in 2010 and 2011 (from which one can derive growth rates), the total revenue for pressure sensors in 2011 for some companies and the total revenue for pressure sensors from 2011 to 2016 (TAM). Therefore, an assumption that must be made to obtain quantitative data is the % of sensor revenue spent on medical for different companies, which is their market presence, etc.

Additional data from market inspection is that MEAS, GE, Honeywell and FSL are market leaders for medical pressure sensors.

Key pressure players
Honeywell (Sensing&Control)
GE Measurement & Control
Measurement Specialties (MEAS)
Freescale (FSL)
STMicroelectronics (STM)
Silicon microstructures (Elmos group)
GEMS sensors&controls (Medical Sciences)
Omron electronic components
Kavlico
Fujikura
Analog Devices (ADI)
Melexis

Fig.5.30. *Key medical pressure semiconductor sensor suppliers by sensor type with a high (dark blue) or low (light blue) degree of certainty* (Source: own market inspection)

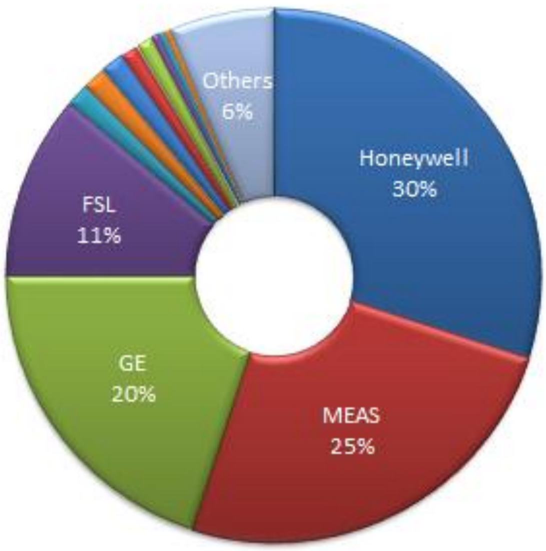

Fig.5.31. *Medical pressure semiconductor sensor supplier's revenue shares* (Source: own Competitor Model)

Regarding an application-based portrait of the market, this is how it looks like:

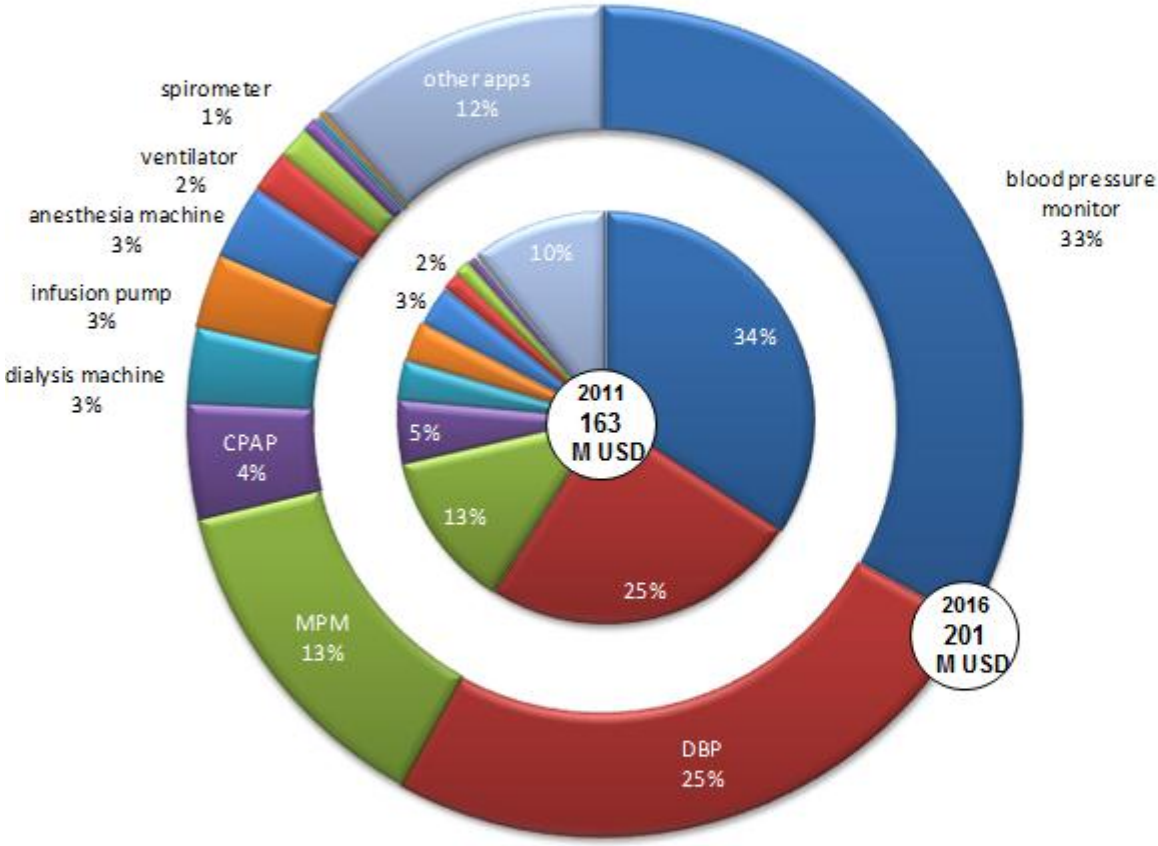

Fig.5.32. *Worldwide medical pressure semiconductor sensor revenue split by application in 2011 & 2016* (Source: own Market Model)

The pressure sensors market is expected to grow at a 4% $CAGR_{11\text{-}16}$ and reach 201 M USD in 2016. It is a fairly mature market.

Blood pressure measurement accounts for a rough 70% of the total pressure sensors market (~140 M USD in 2016). It is distributed between DBP (high unit volumes, low ASPs of ~1/2 USD) and blood pressure monitors (including MPM, with ASPs of ~6 USD).

Other major applications include respiratory devices (CPAP, ventilators, oxygen concentrators, conservers and compressors, nebulizers, spirometers and neonatal care units) with ~10% of the market (~20 M USD in 2016) and dialysis machines, infusion pumps and anesthesia machines with another rough ~10% of the market (~20 M USD in 2016).

The rest of the market is full of a myriad of niche medical applications within the clinical segment (i.e. hospital usage).

Innovative applications include: implantable pressure sensors (i.e. CardioMEMS Corporation) and electronic toothbrushes (Braun Oral B and Philips Sonicare).

Pressure measured is typically gauge or differential, regarded in the market as barometric pressure under 5 PSI. Pressure measurement, however, in some cases, can be done interchangeably in some applications with flow sensor technology and vice versa. Pressure sensors can even act as a switch[39] (upon a certain pressure threshold).

A complete list of medical devices currently using semiconductor pressure sensors are: electronic toothbrushes, glucose meters, blood pressure monitors, blood analyzers, gas chromatographs, infusion pumps, dialysis machines, spirometers, CPAP, MPM, nebulizers, external defibrillators, electronic beds and chairs, ventilators, suction units, surgical robots, anesthesia machines, fetal heart rate monitors, gastric bands, catheter-based surgical procedures, blood auto transfusion devices, waste evacuation systems, oxygen concentrators, oxygen conservers, spinal column testers, hospital gas monitoring systems, baby delivery systems, body heat exchange systems, ocular surgery, organ transportation and transplant, cataract aspiration systems, surgical fluid management systems, dental instruments, etc.

High-revenue applications

The medical semiconductor pressure sensors market is dominated by one main application: blood pressure measurement. No single application is expected to vary significantly its revenue market share in the upcoming years. The headline should read: “blood pressure measurement: an opportunity for existing automotive pressure products.”

Blood pressure measurement

Blood pressure measurement and monitoring (8-16 kPa, up to 24 kPa for hypertension) is the most common use of pressure sensing devices within medical applications, for it is crucial in most surgical procedures and interventions.

Blood pressure measurement is the single highest revenue application in the medical pressure sensors market[40], it accounts for around 70% of the total revenue (117 M USD in 2011).

Top customers include Omron and Microlife (~30% market share) and A&D Lifesource.

Typically, blood pressure measurement may use both disposable and non-disposable pressure sensors. Disposable blood pressure sensors are mainly used on intravenous line, generally in surgical procedures with or without a catheter (i.e. SMI). ASP is ~1/2 USD. Whereas non disposable blood pressure sensors are applied in both home use (typical blood pressure cuff) and clinical use monitors (MPM as a raising application). ASP is ~6/7 USD.

Common technical features include: pressure range up to 50 kPa, ±2,5 accuracy, ±0,5% static accuracy, temperature compensated 0°C to 60°C and specialized packaging required.

Today, blood pressure measurement can be done in many different ways (even with ultrasound systems under research).

Fig.5.33. *Typical blood pressure measurement devices: from left to right: disposable, MPM and blood pressure cuff*

<u>Respiratory devices</u>

Respiratory devices are a cluster that contains CPAP devices, nebulizers, oxygen therapy devices (concentrators, compressors and conservers), ventilators, spirometers and neo natal care units (also called incubators). However, CPAP is the single biggest application within this cluster. Functions vary depending on the device, but typically are used for assisted breathing in patients (i.e. CPAP is used to treat sleep apnea disorders; nebulizer is used to treat asthma, etc).

Together, they add up to around 10% of the medical pressure market's revenue (~16 M USD in 2011). ASP is ~6/7 USD.

The pressure sensor's function is typically to monitor or measure air (gas) pressure.

Top customers include: Invacare, ResMed, Respironics and Delphi Medicals.

Common technical features include: 0-7 kPa for ventilators and 0-3 kPa for CPAP (very low pressure), ±0,5% static accuracy, high sensitivity, temperature compensated -20°C to 60°C and sophisticated packages required.

Fig.5.34. *Typical CPAP device* (Source: Dreamstime)

Dialysis machine, anesthesia machine and infusion pump

This cluster includes in general complex machines and procedures that require typically more than one pressure sensing device.

Together, they count for another 10% of the medical pressure sensors market (~16 M USD in 2011).

Dialysis machine: replacement of some kidney functions such as filtering the patient´s blood. The pressure sensors measures arterial and venous pressure fluctuations while clean-up.

Anesthesia machine: administers drugs to eliminate pain and maintains a mixed balance of medical gases (air, O_2, N_2O + isoflurane) in the body. Pressure sensors measures gas pressures to and from the patient. 2 to 3 disposable pressure sensors may be used in each intervention, a part from the durable sensors that form part of the machine itself.

Infusion pump: deliver fluids, including nutrients and medications such as pain relievers, antibiotics and chemotherapy drugs, into the patient´s body in controlled amounts. The pressure sensor measures the dosage pressure of administered fluids.

Fig.5.35. *Typical anesthesia machine* (Source: procrna)

A spotlight on innovative applications

By market inspection, one might make a qualified guess that the future of blood pressure measurement and monitoring might tend towards implantable pressure sensors.

An implantable pressure sensor would be used to treat common diseases and disorders such as: heart failure, hypertension, aneurysms and sleep apnea. Even typical pressure measurement and monitoring could be a possible usage. Hypertension is a disease affecting many people, and the risk increases with age. Left untreated, it can lead to stroke, heart attack, congestive heart failure, and kidney failure.

The rationale behind of this assertion is threefold. First, to avoid expensive hospital costs and address unmet clinical needs (reduce the number of hospitalizations). Second, because more accurate internal and frequent measurements allows earlier detection and more efficient and individualized treatment (which is in conjunction with the healthcare trends mentioned in earlier chapters). Third, frequently, the target measurement is most accurately obtained through internal detection. Also, the fact that some of the biggest worldwide suppliers of medical devices (i.e. Boston Scientific and St. Jude Hospital) have bought companies that has developed devices in this field) might be a hint on the attractiveness and possible evolution of this segment.

The technology that an implantable pressure sensing this device would probably use is telemetry and RF power and data transmission. The pressure sensing technology would consist of a fixed plate and a movable plate in which pressure varies the position of the movable plate.

This market transition would be, however, slow and forecasted to start to take place in a ten year time frame (long term perspective). The reasons for it is because today this represents a highly innovative application field, with a few thousand units being sold and tested in patients; most of the blood pressure measurement is done with state-of-the-art procedures described above. Plus, these mostly experimental devices are being submitted to trials and FDA approval; therefore need to be further enhanced to be commercialized.

Requirements are stringent and include reducing bulky and invasive procedures (through telemetry, RF power and data transmission; reduce battery and memory size, and the electronics associated with data processing), biocompatibility, hermetical seal, not exceed electromagnetic radiation (<10 mW/cm2) and tissue heating levels (<1°C) and ISO10993 compliance. The device should undergo testing for cytotoxicity, sensitization, irritation, system toxicity, subacute and subchronic, toxicity, genotoxicity, implantation, hemocompatibility, chronic toxicity, and carcinogenicity[41].

Today, there are several companies and research centers that are working in the area of innovative solutions for blood pressure measurement. Some examples are:

- CardioMEMS: wireless sensing designed for proactive management of heart failure patients (pulmonary artery), hypertension (radial artery) and aneurysms (aorta).

- Inspire Medical: pulmonary pressure sensor implanted in the chest, together with a pulse generator similar to a pacemaker. To treat Obstructive Sleep Apnea (OSA). Might render obsolete CPAP devices (reduces the burden to sleep with a mask). Patient enrollment was expected in Jan 2011.

- Millar: fully implantable pressure transmitter with wireless inductive power charging (partnership with Telemetry Research). Mounted at the tip of a catheter, can measure pressure in almost any location. Applications may include cardiovascular, sleep research, toxicology, safety testing, neuroscience and behavioral studies.

- Tronics: implantable pressure sensor platform.

- ISSYS: pressure monitoring system for Congestive Heart Failure patients; implantable micro-device containing a MEMS pressure transducer, customized electronics and a telemetry antenna.

- Medtronic: chronicle device, implantable hemodynamic monitor for heart failure monitoring.

- Remon Med: implantable pulmonary pressure sensor. In 2007 absorbed by Boston Scientific.

- Savacor: implantable sensor in left atrium. In 2005 absorbed by St. Jude Hospital.

- Fraunhofer Institute: implantable blood pressure sensor (artery, bladder, eye).

- Purdue Researchers: piezoelectric-based technology that uses the low frequency of rap music to power an implantable pressure sensor. Size: 3 cm x 5 mm. Implanted in areas such as the bladder, uterus, digestive system or lung. To be commercialized.

6.2.4. CMOS Image sensors

An application-based portrait of the CMOS image sensors medical market reveals that there are three main medical applications (digital X-ray imaging applications, endoscopy applications and camera pills) that together add up to over 95% of the total market in terms of revenue share.

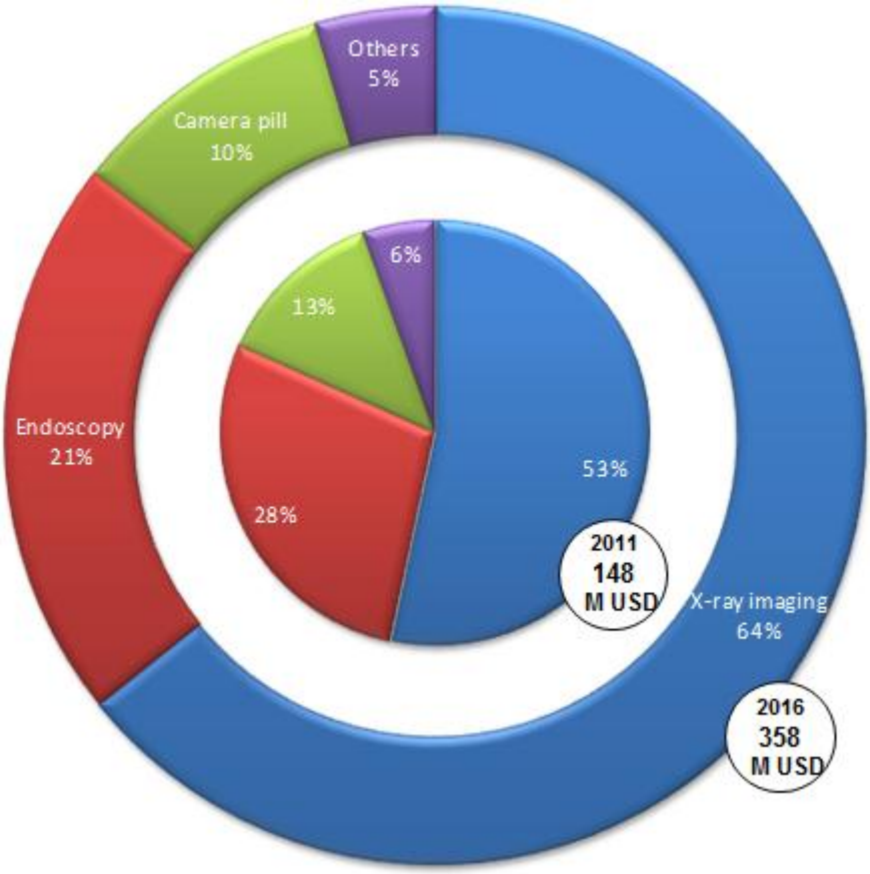

Fig.5.36. *Worldwide medical CMOS image sensor revenue split by application in 2011 & 2016* (Source: Yole)

The global CMOS Image Sensor market reveals high revenue potential; it is expected to grow at a 19% CAGR11-16 and reach 358 M USD in 2016.

X-ray imaging will account for 64% of the total market in 2016 (~230 M USD, 24% $CAGR_{11\text{-}16}$). It includes dental imaging, real time imaging, general radiography, mammography and tissue biopsy and small animals veterinary. It is the single biggest application and it is expected to outgrow the rest over the next coming years.

Endoscopy will account for 21% of the total market in 2016 (~75 M USD, 13% $CAGR_{11\text{-}16}$). It includes laparoscopy, arthroscopy, urological, bronchoscopy, hysteroscopy, etc.

Camera pill will account for 10% of the total market in 2016 (~36 M USD).

Other innovative applications include: retinal implants (i.e. Valtronic).

CMOS image medical sensors are typically high-end products, sold at an average ASP of ~28 USD in 2011 (price range goes from 10 USD to 1000s of USD). There is a global trend towards BIS (back side illumination) CMOS.

Most players are offering application specific tailored packages. Targeted sensor features include: chip size miniaturization and low-light performance.

CMOS is replacing CCD technology (and fiber optics) in medical applications (general trend as well, not only in the medical segment). Advantages are: higher integration and lower bill of materials (reduced chip count, cost and board space).

Low-cost and disposable CMOS imagers (3D Wafer Level Packaging with Through Silicon Via) today are entering the market, targeting less invasive surgical procedures (i.e. Cypress and MIS).

Key CMOS image sensor suppliers include: Omnivision, Altasens, Aptina, Awaiba, Foveon, Sigma, Micron, Pulsa, Dalsa and e2V.

High-revenue and innovative applications

Digital X-ray imaging

Digital X-ray imaging is the use of X-rays to view a non-uniformly composed material such as the human body. By using the physical properties of the ray an image can be developed which displays areas of different density and composition.

X-ray digital imaging applications include: dental panoramic 3D, intraoral real-time imaging (cardio, fluoro, angio, neuro…), general radiography (thorax, orthopedy…), mammography and tissue biopsy and small animals veterinary. Amongst the key market drivers worth mentioning are dental panoramic and mammography applications.

Traditionally, static X-rays have dominated the market. Today, also hand-held portable X-rays are available and their use is growing.

Dalsa (CA) and e2v (UK) are clearly leading players in this area providing high-end and custom image sensor solutions.

Pixel pitching ranges from 20 to 100 microns with a CMOS image sensor chip size of up to 11200 mm^2 in some applications. It is a low volume, high-end application, with average selling prices ranging from 650 to 1800 USD.

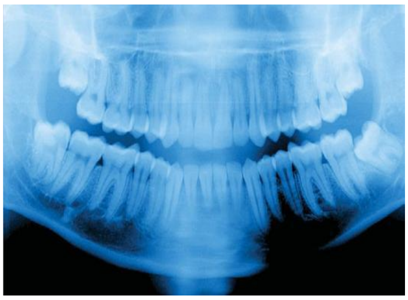

Fig.5.37. *Typical dental imaging X-ray image* (Source: Yole)

Endoscope

An endoscope is a medical instrument used to examine the interior of a hollow organ or cavity of the human body. Traditional endoscopes place image sensors at the back of the assembly never in contact with the human body. Modern endoscopes place cameras at the tip of the endoscope. There are up to 17 different endoscopy procedures.

The adoption of endoscopes using CMOS image sensors is expected to grow (in terms of volume, not of revenue share) in the next 5 years due to the cost of ownership of today's rigid and reusable endoscopes, featured with CCD technology. CMOS image sensors can be produced at very small chip sizes in high-volume and low-cost facilities. Plus, they are less invasive and allow for further patient's safety. An innovative example might be Fujikura´s miniature CMOS based imaging solution, with <1.5 mm diameter, promoting single use (disposable) imaging tools.

This is a high volume, low-end application, with ASP ~10 USD and CMOS image sensor chip size of 1-4 mm^2.

Fig.5.38. *Digital Endoscope with CMOS image sensor placed at the tip* (Source: Yole)

Camera pill

As previously mentioned, a camera pill (smart pill capsule) is a battery-operated wireless device that with a camera videos its descent into the stomach and through the small intestine as it is swallowed, enhancing traditional gastro intestinal endoscopy techniques.

Given Imaging and Smart Pill Corp are the main application suppliers. Omnivision partnered with BC Tech for the development of miniature medical camera chips. The ultimate goal is to be able to integrate a complete miniaturized medical sub-system with LED + transceivers + imager + optics within the same “camera cube.”

It is a high volume, low-end application, with an ASP ~20 USD.

Fig.5.39. *Typical camera pill* (Source: ISuppli)

Retinal implant

Retinal implants are used to restoring, partially, the sight to the blind.

It is the most innovative application field within CMOS image sensors, pioneered by companies like Valtronic. Research is being done at Stanford University and IIP technologies, as well. It needs further investigation to understand its potential.

Fig.5.40. *Retinal implant* (Source: Valtronic)

Conclusions

Outcomes of this study indicate that the global medical semiconductor magnetic sensors market reveals low revenue potential; as most of the applications are yet innovation fields. High-revenue applications include hearing aid/cochlear implant, pacemakers/defibrillator implant and smart pill capsule. Some innovation fields include liquid handling systems (such as automatic coding of chariots, electronic pipetting and blood analysers), medication dispensing cabinets, prosthesis and rehabilitation, body motion reconstruction technology, glucose meters and viral detection.

The global medical semiconductor pressure sensors market seems a fairly mature market, with order of magnitude higher revenue potential compared to the magnetics market. The gross part of the revenue comes from blood pressure measurement, followed by respiratory devices (such as CPAP), dialysis and anaesthesia machines, and infusion pumps. Innovation fields include implantable blood pressure sensors.

Based on the fore-mentioned outcomes, a set of potential business opportunities for IFX have been acknowledged.

In the magnetic sensors arena, this summarises in three basic opportunities. First, IFX could attempt to cross-sell existing magnetic sensor products from other mass market applications (such as BLDC for motor control) to gain market insight and contacts. Second, IFX could invest in derivatives (for magnetic switches) to completely fulfil innovative applications such as those for reed switch replacement (such as hearing aid, pacemaker and ICD implants). Third, this report suggests that the key investment opportunity is magnetic beads for viral detection with spintronics sensors, which is forecasted to have a huge revenue potential.

Regarding pressure sensors, two potential opportunities have been identified. First, IFX could try to address the blood pressure and respiratory devices current market with existing automotive products. Second, it suggests that the future of blood pressure measurement might tend towards implantable pressure sensors, with a non-significantly different technological basis; and, therefore, investing in derivative products might be fundamental to succeed in this area.

Hence, focusing on the development of derivative products to pioneer the commercialization of innovative medical applications, with a forecasted huge revenue potential, might be the best option for IFX.

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