CHAPTER 2: SIMULATION MODEL OF THE CEA-LETI CAPACITIVE MEMS

2.1 SOFTWARE DESCRIPTION

The software which is used in the simulations is ADS/Momentum developed by Agilent Technologies. This software has two parts: ADS which is in charge of the SPICE model of the MEMS and Momentum which studies the electromagnetic response of the device. Since the designs are already fabricated, the way to use this software is to define a layout which fits with the measures and then define an SPICE schematic which fits with the Momentum model.

The method that is used by Momentum to analyze the models is the Method of Moments (MoM). This model is oriented to structures of 2.5D that means that is a 2D model which takes into account, moreover, only the perpendicular direction to the 2D model. For example, in a MEMS, when a VIA is defined between the bridge and the ground plane, this via only support currents in the perpendicular direction of the ground plane.

There are two reasons for using a 2.5D simulator in front of a 3D simulator. The first one is that the relation between the gap in MEMS and the width or length is very high so the deviations in the direction of the perpendicular planes does not affect at the model. The second one is the time of simulation which is highly reduced. So as to see if a 2.5D simulator is enough, a comparison between Momentum and HFSS (3D Simulator by Ansoft) (Figure 2.1) is done arriving to the conclusion that there are no differences in the results (Figure 2.2). So, the chosen software is Momentum so as to save time and resources simulation.

Figure 2.1: Layout of AMA design in Momentum (left) and 3D model of HFSS of the same design (right)
The algorithm to proceed with the simulation has four steps: Definition of the substrate, Design the geometry of the model, Meshing and Results. Below, they are specifically defined for the models presented in Chapter 3. The reason for their order is because is similar to the fabrication process in the foundry: definition of the substrates, design of the masks of the process and finally test.

2.2 DESCRIPTION OF THE MODEL

As it was said in 2.1, the steps followed for the design of the model are definition of the substrate, design of the model, meshing and results. The model starts with the theoretical values of the parameters of the switch (first approach) and, with the results of these simulations a more refined model is calculated taking into account the measures given by CEA-Leti.

2.2.1 FIRST APPROACH OF THE MODEL

In Figure 2.3 the cross-section of MEMS in both states is showed. The design of the first approach should take into account the substrate and the layers drawn there. The specifications of substrate are given by CEA-Leti and should be introduced in the layout model of Momentum. Moreover, using the values presented in Table 2.1, the layers of the conductors, dielectrics and VIAS are proposed also in Table 2.1.
Table 2.1: Definition of the substrate and Layers for the model

<table>
<thead>
<tr>
<th>Material</th>
<th>Dielectric constant</th>
<th>Thickness (um)</th>
<th>Loss Tangent</th>
<th>Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>--</td>
<td>1</td>
<td></td>
<td>Bridge</td>
</tr>
<tr>
<td>Air</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>VIA_air</td>
</tr>
<tr>
<td>SiN</td>
<td>7.35</td>
<td>0.2</td>
<td>0.002</td>
<td>VIA_SiN</td>
</tr>
<tr>
<td>Gold</td>
<td>--</td>
<td>1</td>
<td></td>
<td>Line</td>
</tr>
<tr>
<td>Silicon</td>
<td>11.9</td>
<td>500</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

The layers defined as VIA_SiN, Bridge_off and VIA_air are not physical layers. They are the way that Momentum uses to represent the currents that go from bridge either to dielectric or to the ground planes. However, VIA’s layers are used in the masks for the fabrications so as to define the anchor of the MEMS while Bridge_off is dismissed.

With the proposed model, the results of the simulations are compared with the measurements so as to develop the second approach. In Figure 2.4 the comparison between the model and the measures are presented. As it can be seen there is a huge difference in the resonance frequency that could be due to the fabrication process. For this reason a second approach is proposed in following parts.

Figure 2.4: Comparison between model (dark blue) and measures (orange and red) in DOWN position
2.2.2 SECOND APPROACH OF THE MODEL

The fabrication problems mentioned before are basically two: roughness of the dielectric and a parasitic air gap between the dielectric and the bridge in DOWN state. For these problems two different solutions are proposed and evaluated. The first one is the change of the dielectric constant of the dielectric and the second one is the insertion of another air gap in the substrate definition. Below, both are discussed and compared.

From a physical point of view, the change in the dielectric constant is not correct because the used material implies its dielectric constant. However, from the point of view of a designer, this approach helps to have an idea of the behavior of the contact surface (roughness and planarity). In Figure 2.4 the results for the model with a synthetic dielectric constant of 1.5 are presented, in clear blue, showing a very good agreement with the measures.

The determination of the synthetic dielectric constant is done using the comparisons of the SPICE model in Annex 1. With the relationship between capacitance and central frequency, the range of values from 1.4 to 1.6 is tested. From the results of the different simulations, the value of 1.5 fits better with the measures.

The other solution proposed is the insertion of the air gap. In this case, the interpretation should be done as a distance between dielectric material and the bridge in DOWN state. This gap introduces a parasitic capacitance which displaces the central resonance frequency. The distance between layers is also computed with the results in Annex 1 arriving to a theoretical value of 0.6um of air gap. This value is changed to 0.1um so as to fit with the measures as it is shown in Figure 2.5.

This solution has a physical motivation and it fits as well as the previous one with measurements. However, the second one needs more time for the simulation because a new region in the substrate is
In conclusion, from the two proposed solutions, the first one is more suitable from the point of view of computation time. Since the results are really similar; the computation time becomes an important factor of decision. The model of this displacement of frequency should be also taken into account because is a defect of the fabrication process.

2.3 CONCLUSIONS

In this Chapter, the model for the simulation in Momentum software of CEA-Leti designs is presented. In the model, a synthetic dielectric constant is proposed so as to model the displacement of the frequency between a first approach model and the measures. This type of approximation presents good agreement with measures despite not having a physical reason.

From the model of the air gap, it can be concluded that a defect of the fabrication process is present and should be studied deeply. This kind of problem is usually due to depositions of materials in the fabrications process over layers which are not as flat as desired. The detection of the size of the gap and the effect can help in other fabrication processes so as to avoid the problem.

Finally, despite detecting this technological problem, it is concluded that the fabrication of the devices presented in this paper should be considered. The viability of the fabrication should take into account that the predicted specifications of the models can not be as ideal as presented. Moreover, this deviation could depend also on the wafer where no measures are given by CEA-Leti.