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Compact Device for CO_2 Optical Sensing using Macroporous Silicon Photonic Crystals

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1. Abstract

A photonic crystal based on a macroporous silicon structure has been fabricated and successfully used for the detection of carbon dioxide. In this paper, the device and the measurement results are presented. The sensing device here described uses an optical approach to the detection of the gas. The use of a photonic crystal allows creating a compact device working in the medium infrared spectral range. A 700 nm square lattice macroporous structure was fabricated by electrochemical etching, creating a photonic gap centred at the 4.2 µm, a CO_2 absorption line. The obtained results rely only on the absorption spectra measurement.

2. Introduction

Gas sensing, detection and quantification can be done employing a broad variety of techniques [1]. Commercial sensing devices, depending on their application, have several requirements in size, portability, sensitivity and selectivity. Commonly found for commercial applications are sensors based on metallic oxides or polymers. Though these type of sensors fulfil the first two premises, there are somewhat lacking in others such as selectivity or response times. Furthermore, some kinds of sensors can have high power demand, and may suffer degradation, either from aging, or contamination. On the other hand, optical sensing devices usually have good sensitivity and excellent selectivity and have fast responses, but often are laboratory grade equipment. Recently, compact devices based on the measurement of an optical response have been described [2]; other works [3] propose the use of macroporous silicon for gas sensing.

3. Fabrication and Measurement

Macroporous silicon structures used in this work were fabricated using the light assisted electrochemical etching technique (EE) for silicon described in [4]. N-type wafers were etched in a hydrofluoric acid bath controlling the pore profile by light modulation. The fabricated structures are square lattices of ordered pores with a 700 nm pitch and pore diameter around 500 nm with a soft modulation, as seen in **Fig. 1**. The structures where characterized by FTIR reflectance measurement in the MIR range from 2 µm to 20 µm. A reflection peak can be observed (**Fig. 2**) in the 4.2 µm CO_2 absorption line. Afterwards the sample was placed in an enclosed cell through which CO_2 at different concentrations flowed. Reflectance was measured at normal incidence through a potassium bromide window at a 0.5 mm gap from the sample.

4. Results and Discussion

The fabricated macroporous structure as shown in **Fig. 2** has a 30% reflectance peak at the CO_2 absorption line. Though this peak is good enough, better values should be possible. As the SEM image in **Fig. 1** reveals, this is due to the soft modulation and structure irregularities. Work is being done to improve the reflection peak, improving the reflectance, and it also should increase sensitivity. From the reflectance measurements, absorption spectra for CO_2 concentrations from 5% to 50% was extracted, as shown in **Fig. 3**. From the obtained results a clear variation of absorbance can be observed for different gas concentrations.

5. Conclusion

Gas sensing compact devices based on a macroporous silicon photonic crystals have been successfully fabricated with a photonic bandgap at the 4.2 µm absorption line of CO_2. They were tested for several gas concentrations and the absorbance spectra obtained shows a clear relationship with concentration.

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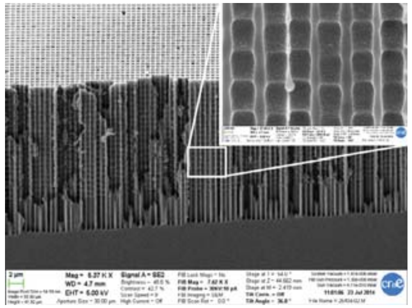

Fig. 1. SEM image of the macroporous silicon photonic crystal fabricated.

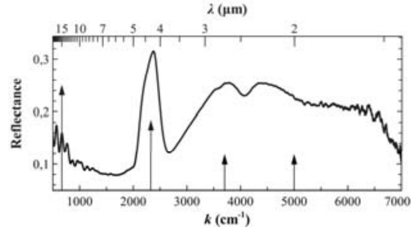

Fig.2. Reflection spectra of the fabricated sample. CO_2 absorption lines are marked as arrows.

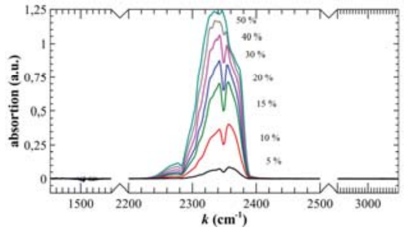

Fig. 3. Absorbance spectra at different gas concentrations.