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Tuning the emissivity of 3D macroporous silicon in the mid-infrared

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1. Introduction

Tailoring the thermal emission of a particular material by using periodic micro-structures has attracted great interest for its potential applications in heating and lighting systems [1] or thermophotovoltaics [2]. Many researchers have focused on thermal radiation from surface gratings, since they present anomalous spectral emissivity [3]. In particular, both metallic and dielectric gratings can be designed to produce sharp emission peaks which can be controlled with the grating parameters [3-5]. Three-dimensional (3D) photonic band gap (PBG) materials are particularly flexible in managing and confining light and, therefore, they are excellent candidates for controlling thermal radiation [6].

Macroporous silicon [7], consisting of periodic arrays of etched pores in hydrofluoric acid (HF) solution, is a versatile material that provides large-area, high-quality and thermally-stable microstructures. It features full three-dimensionality, well controlled pore distribution and growth, and scalable dimensions in a range from 0.5 µm up to 100 µm. Silicon 3D structures operate at infrared wavelengths, efficiently reducing the emissivity inside the PBG regions. We present here several Si microstructures and their emissivity/reflectivity responses measured by FT-IR spectrometry.

2. Results and discussion

Macroporous silicon is obtained after photo-assisted electrochemical etching of *n*-type silicon in HF. Prior the etching, the front side of the samples is pre-structured using standard photo-lithography in order to define the desired pore distribution. During the electrochemical etching, the diameter of the pores is defined by the photogenerated current and as a result, the pore diameter can be modulated in depth by controlling the photocurrent as a function of time. A periodic photocurrent profile is used in order to introduce a periodicity in the third dimension of the crystal. Figure 1 shows some examples of achieved modulated profiles.

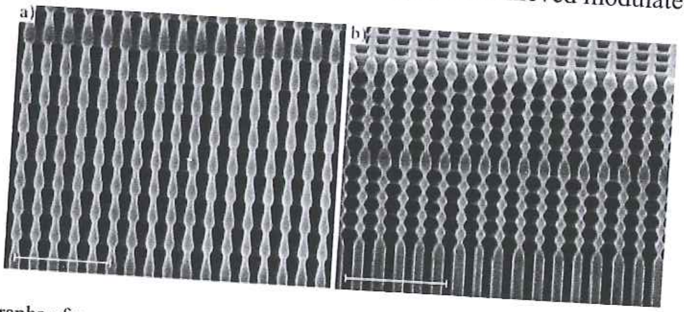

Fig. 1: SEM micrographs of macroporous silicon samples with modulated pore diameter in depth. (a) asymmetrically modulated pores; (b) straight and symmetrically modulated profile with a defect layer. The scale bars are 30µm.

The studied structures show PBG in the longitudinal direction of the pore. In figure 2 we can see various structures fabricated with different periods along the pore axis, their reflectivity at room temperature and thermal radiation at 400ºC. It is clear how, in the PBG region, the emissivity of the macroporous Si is mainly suppressed, and how it can be tuned by structure's parameters.

By controlling the amplitude of the modulation (ratio between diameter maxima and minima) and the period length (distance between two maximums) the bandwidth and spectral position of the PBG can be modified. In addition, the overall optical response of the structures can be shifted toward higher frequencies by scaling-down the dimensions of the structure in all three dimensions. As an example, Figure 3 shows side-by-side the thermal radiation spectra of two samples, one with 4 µm (Fig. 3a) and another with 2 µm (Fig. 3b) periodicity, the emissivity is inhibited in different spectral regions shifted by a factor of 2 when scaling-down the lattice periodicity.

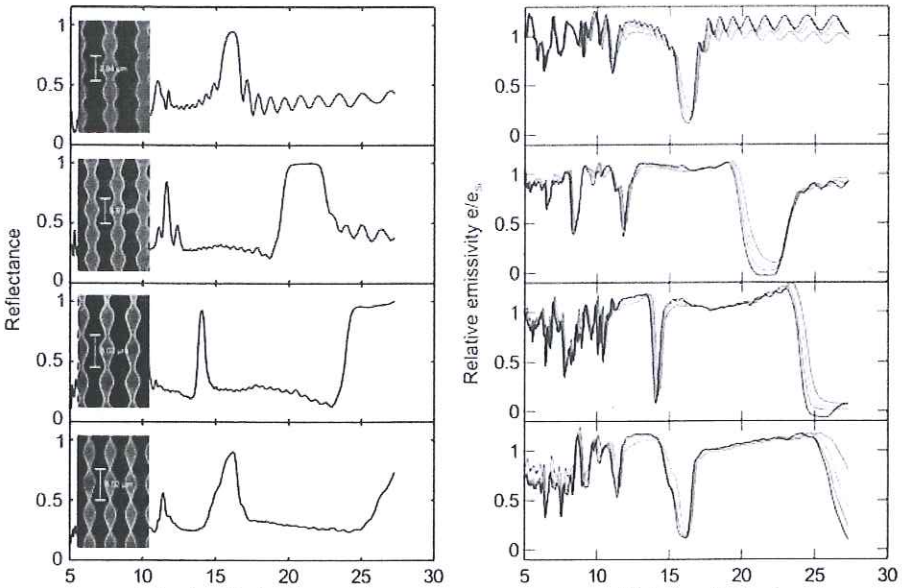

Fig. 2: Room temperature reflectivity and emittance spectra of 3D macroporous silicon with different periodicities along the pore axis. Emissivity measurements are performed at 100, 200, 300 and 400 °C and normalized to that of polished silicon at the same temperatures.

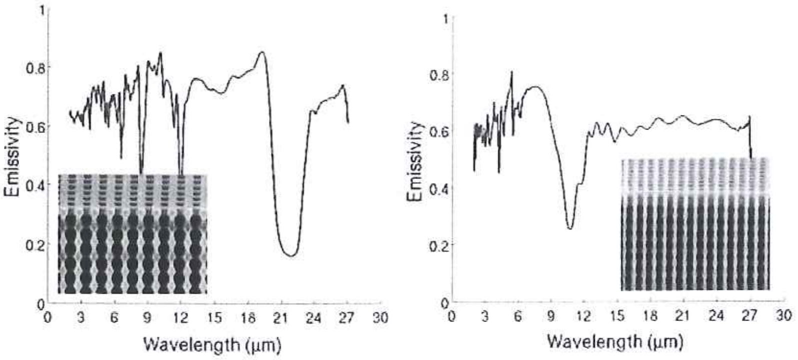

Fig. 3: Comparison of the emittance spectra of 3D macroporous silicon at 400ºC with periodicities in all three axes of (a) 4µm and (b) 2µm. Measurements are normalized to BB radiation. The insets are SEM pictures of the measured structures.

3. Conclusions

Our results show that thermal emission of macroporous silicon can be modified by controlling the structure parameters, making it an interesting material for thermal applications.

4. Acknowledgments

This work has been partly founded by the Spanish Commission of Science and Technology (CICYT) through grant TEC2008-02520.

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