Fabrication of a novel micro-nano-hybrid porous silicon array for photonic crystal application

D.H. Ge[1,2], M.C. Wang[2,3], W.J. Liu[2,3], J.W. Jiao[2]
[1] School of Mechanical Engineering, Jiangsu University, Zhenjiang 212013, China
[2] State Key Laboratories of Transducer Technology, Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences
Shanghai 200050, China
[3] Graduate University of Chinese Academy of Sciences, Beijing 100049, China

PC as a micro-structured material with dielectric constant varying periodically in space, gives us a possibility to successfully control photons and will play an important role in the future optoelectronic fields [1]. One of the most important and useful properties of PCs is the photonic band gap (PBG). Among various methods for the fabrication of PBG structures, porous silicon based technique [2] has received great attention due to its advantages of high surface-area-to-volume ration, low cost, and biocompatibility. Intensive efforts have been made to fabricate PCs based on ordered porous silicon arrays. However, the hybrid porous silicon array based PC structure, which can monolithically integrate micro- and nano-pores, has not been well studied to date. Such hybrid PC structures are expected to offer some attractive features such as tunable photonic bandgap.

Here we demonstrate a two-dimensional hybrid PC structure of ordered porous silicon array. Each unit of the array consists of a centric micro-sized pore and six surrounding nanopores. The micro-nano-hybrid pore array is fabricated by electrochemical etching on partly oxidized porous silicon substrate. The fabrication process is based on photoelectrochemical etching combined with steps of oxidation, chemical mechanical planarization (CMP) and KOH etching. The theoretical calculation of the band structure of a 2D periodic PC comprised of a triangular lattice of air micro-rods surrounded by six air nano-rods is performed with different pore diameters.

N-type (100) silicon wafer with a resistivity of 3-8 Ωcm was used in our experiments. Initial pits with a triangular pattern and 2 μm pitches were first produced. Photoelectrochemical etching was performed under voltage of 2 V with 3% HF and ordered micro-sized pore array with diameters around 1 μm was obtained, followed by an oxidation and a CMP process to form partly oxidized porous silicon and expose the remaining silicon area, respectively. Then a second anodization step was performed and nanosized pores, surrounding the centric micro-pores, were obtained (Fig. 1a). Finally, ordered micro-nano-hybrid porous silicon array was successfully achieved after removing SiO_2 in the micro-pores. The top-view and cross-section SEM micrographs of the hybrid array are shown in Fig. 1b and c. As can be seen from Fig. 1b, the nano-sized pores are quite precisely positioned at the center of the equilateral triangle formed by three nearby micro-pores. Such ordered micro-nano-hybrid pore array can be used as a 2D PC with each unit consisting of a centric micro-pore with diameter of 1.5 μm and six surrounding nanopores with diameters about 200 nm (Fig. 1c).

We calculated the photonic band structure (Fig. 2) of such made 2D periodic PC comprised of a triangular lattice of air micro-cylinders surrounded by six air nano-cylinders in high dielectric (ε=12). The radius of micro-cylinder is $r_1=0.4a$, where a is the lattice constant, and r_2 is the radius of nano-cylinder which ranges from 0 to $1/3r_1$. We note that a complete photonic bandgap between the first and second bands exists for both TE and TM polarizations. Especially for the TE modes (Fig. 2a), there is a large photonic bandgap which is very sensitive to r_2. Increasing the nano-cylinder radius from 0 to $1/3r_1$, the bandgap has decreased almost 50%. Therefore it is convenient to tune the photonic bandgap by simply changing the diameter of nanopores in the second anodization step.

References

[1] J.D. Joannopoulos, P.R. Villeneuve, S. Fan, Nature 386 (1997) 143.

[2] H. Foll, M. Christophersen, J. Carstensen, G. Hasse, Mater. Sci. Eng. R 39 (2002) 93.

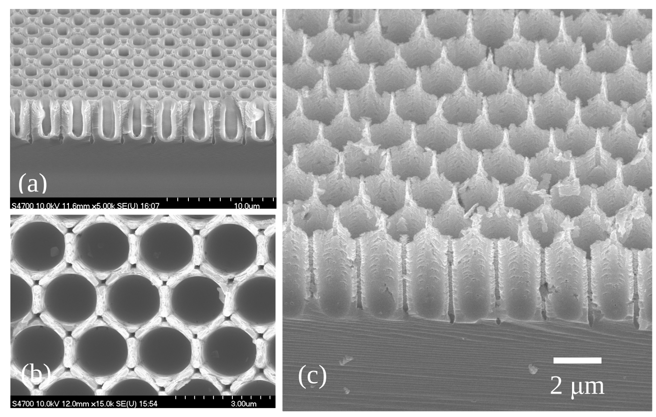
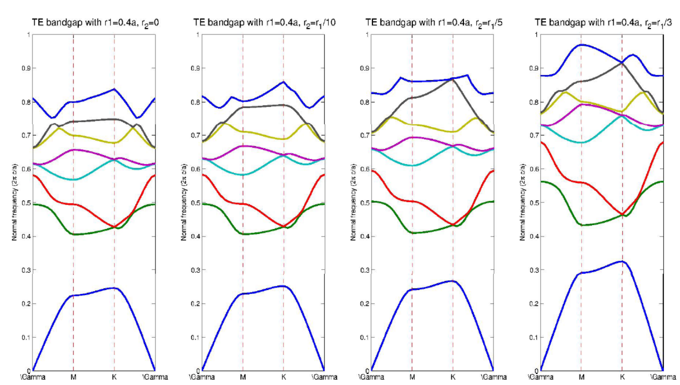
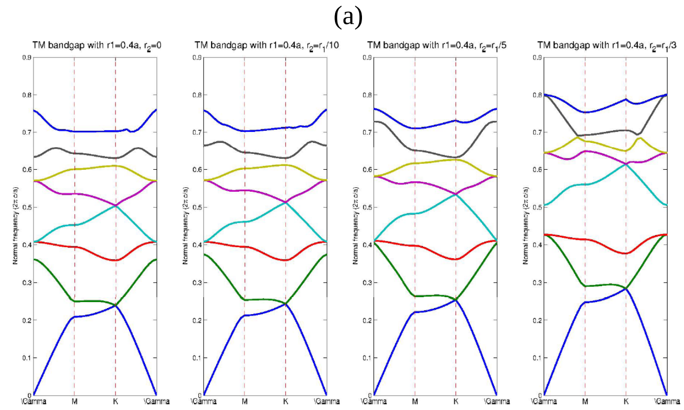


Figure.1 SEM micrographs of the micro-nano-hybrid pore array.



(a)



(b)

Figure.2 TE (a) and TM modes (b) of photonic band structures for a triangular lattice of air micro-cylinders (r_1=0.4a) surrounded by six air nano-cylinders with radius r_2 ranging from 0 to $1/3r_1$ in dielectric (ε=12).