Planarization of High-Aspect Ratio Nanostructures by Infiltration and Pressing of Organic and Inorganic Curable Materials

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Recently, there is increasing interest in fabrication of multi-level three-dimensional nanostructures for many applications such as photonic crystals[1], metamaterials[2], and three-dimensional interconnects in ultra large scale integrated circuits. A key to the realization of these devices is the planarization of each level upon which the next level can be fabricated. While various planarization techniques have been developed[3], there remains a pressing need for simple, rapid process suitable for planarizing high-aspect ratio structures with very low residual layer but without the complicated step of chemical mechanical polishing or long etch-back. Here, we demonstrate that by utilizing organic and inorganic nanoimprintable resist materials, large-area high-aspect ratio photonic nanostructures can be completely filled out and planarized in a quick, simple step with very low residual layer and surface roughness, thereby enabling the rapid prototyping of multi-level devices.

Inorganic sol-gel resists are prepared from a Methytriethoxysilane (MTEOS) sol mixed with aqueous solution under acidic conditions. MTEOS films are deposited by spin-coating on the sample to be planarized and pressed with elastomer PDMS (PolyDiMethylSiloxane) stamp. The sol gel resist is then thermally cured at low pressing pressure of 1.5 bar: an intermediate temperature of 100 ^{0}C is first reached and maintained for 2-3 minutes to evaporate most of the solvent, and then the condensation of sol-gel occurs at a temperature of 130 ^{0}C for 5 mins. The sample is brought back to ambient temperature under the low pressure. The soft PDMS stamp is used to improve the penetration of the materials into trenches and holes, and to obtain a small roughness at the surface. The rms roughness for the PDMS stamp is 2-4 nm. A further advantage to this approach is that the refractive index of the sol-gel can be tuned to suit the desirable optical properties of the planarized device. Fig. 1 shows an example of a device planarized by this approach.

Alternatively, uv-curable nanoimprint resist can also be utilized for the purpose of planarization. The uv-curable resist in its liquid form is drop dispensed onto the sample structure, and pressed with anti-adhesion-treated flat glass template at low pressure in vacuum for less than 1 min. The template-substrate stack is then flood-exposed by uv light for 2 mins. to cure the resist. The template is then separated from the sample. Fig. 2 shows an example of a device planarized by this approach. With the low viscosity of uv-curable resist, it is possible to achieve planarized structure with minimal residual layer in a single press step. Applications in planarizing structures with different aspect-ratio and residual layer thickness, as well as three-dimensional multi-level device fabrication will be discussed.

1. J.G. Fleming *et al.*, Nature **417**, 52 (2002).
2. N. Liu *et al.*, Nature Materials **7**, 31 (2008).
3. G. Subramania, Nanotechnology **18**, 035303 (2007).

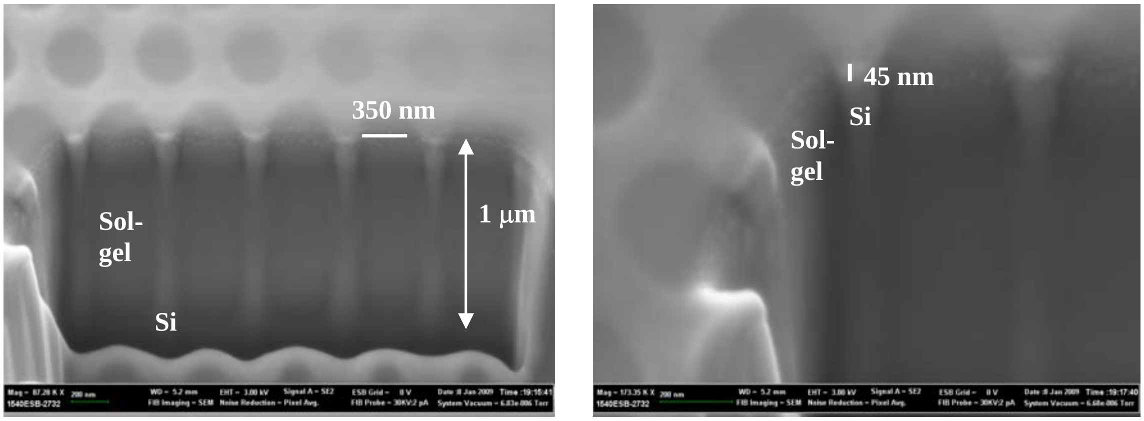

Fig. 1. Cross-sectional SEM images (obtained by FIB) of MTEOS Sol-Gel planarized one-layer Si 2D hole-array photonic crystal slab structure. The depth of the structure is 1 micron and the aspect ratio is 1:3. They show that the holes are completely filled out with a thin residual layer of less than 50 nm. The residual layer can be thin enough so that the next level of devices can be directly fabricated on it. The images are tilt-corrected for 54^0.

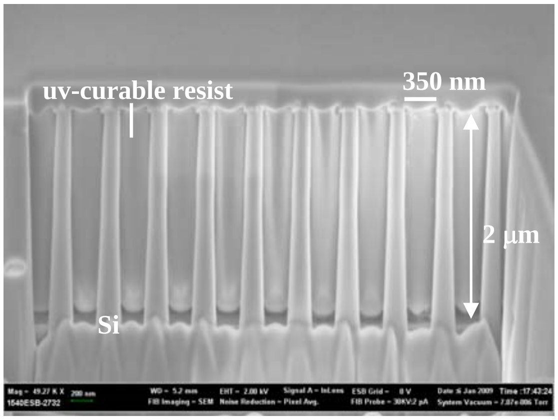

Fig. 2. Cross-sectional SEM image (obtained by FIB) of uv-curable resist planarized one-layer Si 2D hole-array photonic crystal slab structure. The depth of the structure is 2 microns and the aspect ratio is 1:6. It shows that the holes are completely filled out with a thin residual layer of 300 nm. The image is tilt-corrected for 54^0.