X-ray imaging of functional three-dimensional nanostructures

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Three-dimensional (3D) nanostructures are drawing major attention for advanced functionality in nanophotonics [1], photovoltaics, novel 3D integrated circuits and flash memories. The functionality of such nanostructures are set by their complex internal structure. Since real nanostructures inevitably differ from the design, the observed functionality differs from the expected one. It is thus critical to know the structure of a 3D nanomaterial and verify how well it matches the design. Ideally such a technique leaves no traces of the inspection to leave the nanostructure fully functional and ready for integration. We thus introduce traceless X-ray tomography (TXT) as a new nanotechnological methodology to study functional nanostructures on thick substrates “as is”.

Usually, a new nanostructures is inspected by SEM. But only the external surface is then viewed while the 3D structure remains hidden (Fig. 1A). SEM may be supplemented with ion beam milling to cut part of the structure away. This approach is undesirably destructive and irreversible. To achieve nanometer spatial resolution, we employ X-ray holographic imaging [2] that was done at the ESRF beamline ID16A-NI. We study Si 3D photonic band gap crystals made by CMOS-compatible means (Fig. 1A) [4]. These nanostructures are powerful tools to control the propagation and the emission of light [3].

Fig. 1A shows a bird’s-eye view of the reconstructed sample volume of the 3D photonic crystal shown in Fig. 1. The Y Z top face shows the surface of the X-directed pores, similar to the SEM surface in Fig. 2A. The pore alignment determines the 3D structure and is a crucial step in the nanofabrication. In practice, the alignment is controlled by the etch mask for each pore array and by the directionality of the etching. We find that pores are running in the Z direction, whereas in the XY front face, pores are running in the X direction, matching the 3D design of the inverse woodpile structure. Notably the fabricated structure stays fully functional after X-ray imaging as it does not undergo any preparation step. We look forward to new opportunities using speckle imaging with coherent X-rays.

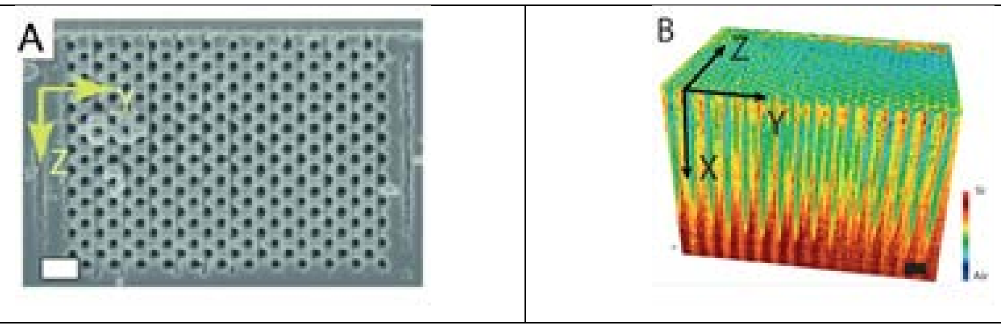

Fig. 1. **(A)** SEM image of the ZY-surface of a 3D Si inverse woodpile photonic crystal from Ref. [3]. **(B)** Bird's-eye view of an inverse woodpile crystal reconstructed from X-ray tomography with 55 nm resolution. The colour scale is the 3D material density ρ(X,Y,Z) interpolated between air and Si.

References

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