Fabrication and applications of sub-micron 2D/3D periodic carbon structures

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The carbon-carbon chemical bond is remarkable, existing as diverse crystalline allotropes diamond (transparent, insulating and hard) and graphite (opaque, conducting and soft) as well as amorphous or glassy carbon. One route to production of glassy carbon material is pyrolysis of an organic precursor. Many of the polymers used in micro/nano lithography such as novolac/phenolic resins, PMMA and SU-8 can be converted into amorphous carbon with the advantage of photo-patternability in the resist state with subsequent conversion to carbon.

Recently we have demonstrated that pyrolysis of high aspect ratio 2D and 3D submicron resist structures created using interferometric lithography results in sub-micron carbon structures which, remarkably maintain their pattern morphology despite undergoing massive shrinkage in the conversion process to carbon. Furthermore, these structures find use in applications owing to the inherent material properties of the carbon combined with the structural properties of the sub-micron patterning created via interferometric lithography.

Figure 1 contains SEM images of 2-D patterned SU-8 derived carbon structures used as a growth mask for defect reduction in MOCVD growth of GaN. Research has shown that epitaxial growth through patterned growth masks reduces defect density in lattice mismatched systems such as the GaN-Al_2O_3 system. Choice of a suitable growth mask for GaN growth is complicated because the growth temperatures are typically > 1000 ºC. Carbon possesses the highest elemental melting point, making pyrolytic carbon a potential growth mask material. Figure 1a shows a cross section SEM image of the SU-8 structure, which after pyrolysis converts to the structure shown in Figure 1b. Figures 1c-d show SEM images of faceted GaN grown through the mask of 1b using a 2-step MOCVD growth reaching 1050 ºC in the final growth phase.

Figure 2 contains SEM images of 3-D patterned negative photoresist-derived carbon structures used as an electrode material for electrochemical applications. Upon pyrolysis in excess of 1000 ºC, the carbon has a nearly metallic DC conductivity. In addition, the lithographically patterned carbon structure possesses higher surface area with accessible pore structure, making these carbon scaffolds ideal electrode structures. Figure 2a shows a top-down SEM image of the negative resist structure, which after pyrolysis converts to the structure shown in Figure 2b. Figure 2c shows an SEM image of ultra-small (1-3nm) Au nanoparticles electrochemically deposited from a gold salt solution. Figure 2d shows an SEM image of electrolessly deposited Paladium coated Au nanoparticles decorating the carbon matrix. These palladium particles show catalytic behavior toward methanol oxidation, demonstrating their utility as a fuel cell electrode.

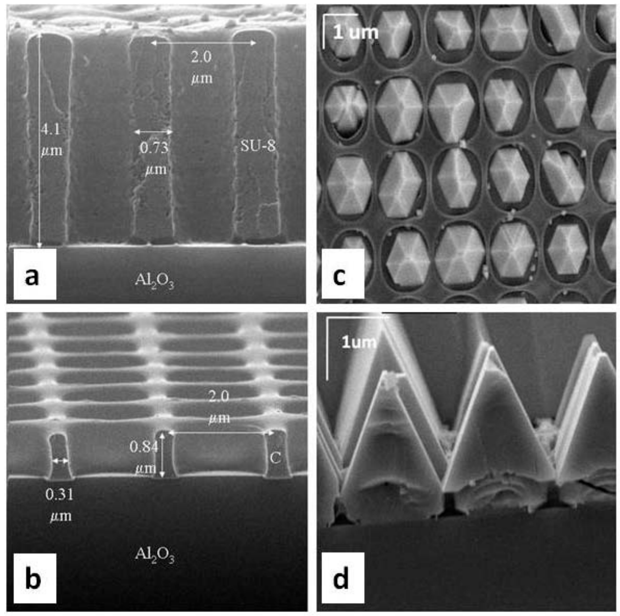

Figure 1. a Cross section SEM image of high aspect ratio 2-D SU-8 structure on sapphire **b** Cross section SEM image of pyrolyzed carbon structure derived from 1a. **c** Top down SEM image of GaN grown in carbon growth mask. **d** Cross section SEM image showing faceted pyramidal GaN growth

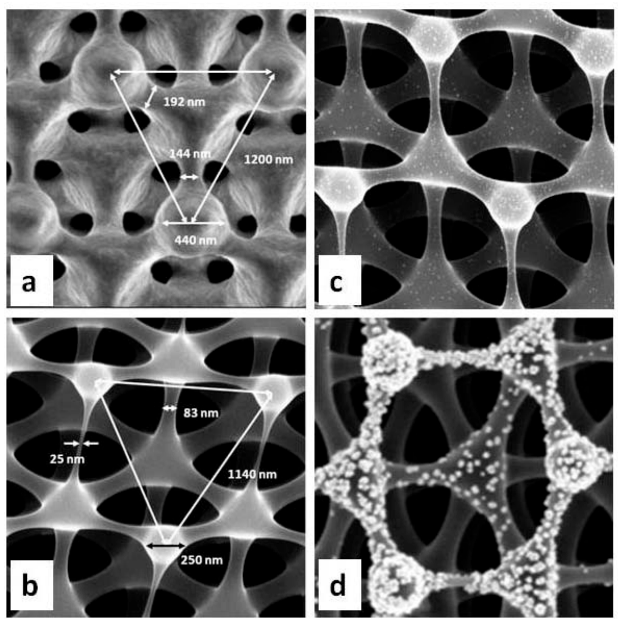

Figure 2. a Top-down SEM image of 3-D NR-7 lattice **b** Top-down SEM image of pyrolyzed carbon structure derived from 1a. **c** Top down SEM image of ultra-small electo-deposited gold nanoparticles on the carbon matrix. **d** Top Down SEM image of electrolessly-plated Pd particles deposited on the Au-nanoparticle decorated carbon matrix.

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