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Coloring with Focused Ion Beam Fabricated Nanostructures

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Interaction of visible light with subwavelength structures leads to generation of unique structural colors, which offer high spatial resolution beating fundamental resolution limit of bright field microscopy [1]. A variety of metallic, dielectric nanostructures have been realized for color filtering applications. Structural colors arising from plasmon resonances in metallic nanostructures, however suffer high optical losses, resulting in loss of color purity in addition to the use of costly noble metals. Dielectric nanostructures, based on Mie resonances offer a viable solution for structural color generation [2]. Silicon (Si), a high index dielectric with low loss in visible spectrum, makes it an ideal choice for low-cost color filtering applications. Fabrication methods, such as lithography along with wet chemical/ dry etching , ion sputtering, thermal dewetting, laser melting and reshaping, nanoimprinting etc. for color generation have been demonstrated, which include multiple steps and are limited to cylindrical/spherical shapes. Recent developments in focused ion beam (FIB) techniques for 3D nanostructure fabrication [3] extend its application for fabrication and exploration of color filters for enhanced color purity and fabrication simplicity without requiring any masks or multi-step operation.

In this work, we use FIB for novel Si nanostructure fabrication for color filtering applications. Gallium FIB in a dual beam FEI Quanta 3D system was used for milling 3D nanohole structures with a unique tapered geometry utilizing the Gaussian nature of incident ion beam. The spacing (period) between the holes was controlled using beam overlap function with multi-pass FIB scans to minimize redeposition during ion milling. The fabricated periodic array of subwavelength holes allows light manipulation over visible spectrum and leads to generation of structural colors, which are clearly observable in a bright field optical microscope. An array of FIB fabricated tapered nanoholes is shown by scanning electron microscopic (SEM) images (Fig. 1a) and generation of blue color through light filtering observed in the bright field optical microscopic image (inset Fig. 1a). Further, the diameter and the period of nanoholes are controlled for tuning the structural color, which is demonstrated in Fig. 1b through a wide color palette. Results reveal the novel and simplified fabrication solution for color filtering applications without additional steps that are essentially required in conventional approaches. As a demonstration, process capability is shown through fabrication of a Kangaroo and word ‘NANO’ (Fig. 1c, d). In summary, successful demonstration of color filtering through unique nanostructures fabricated via FIB provides a new approach having potential for refractive index sensing, spectral imaging etc. in addition to color filtering [4].

References:

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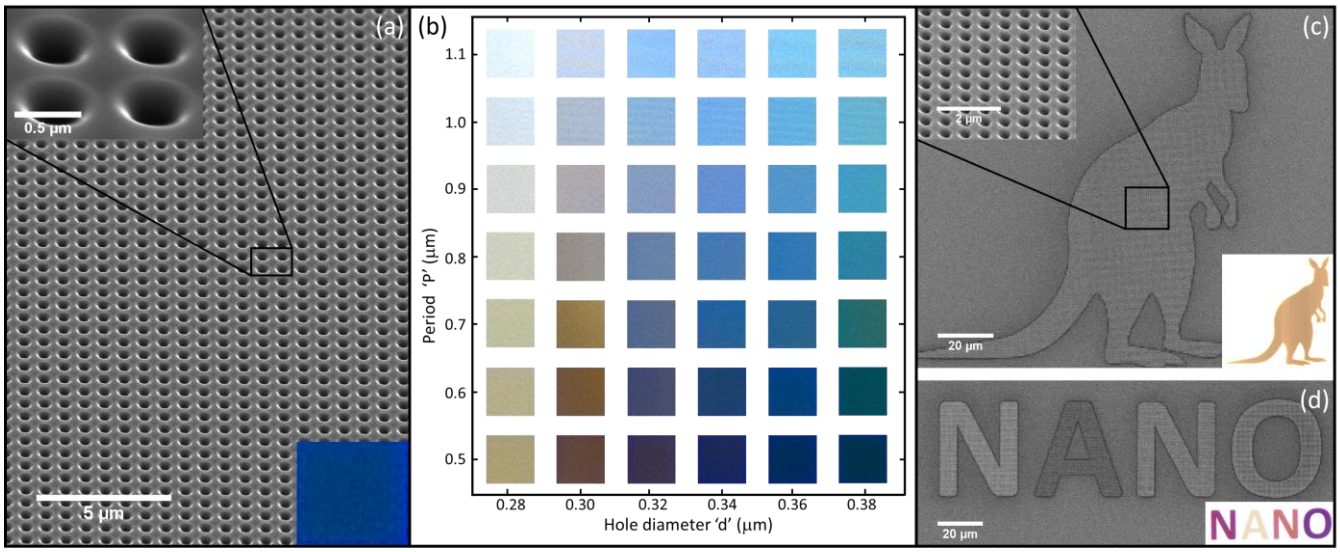

Figure 1. (a) Low, and high resolution (top left inset) SEM images of an array of subwavelength holes fabricated with FIB; bottom right inset shows bright field optical microscopic image demonstrating generation of blue color. A wide color palette is shown in (b) with optical microscopic images of fabricated color filters. Demonstration of color filtering on Si: (c) SEM image of a Kangaroo, comprised of FIB fabricated nanoholes (shown via magnified SEM image in top left inset) including corresponding optical microscopic image in bottom right inset; (d) Letters printing with different colors: SEM image of word 'NANO' and corresponding optical microscopic image in the inset.

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