Lithographically-Defined Nanostructures for Color Plasmonic Printing

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The aesthetic beauty of nanoplasmonic structures is manifested in their ability to display rich color tones. These nanostructures display colors that are different from their bulk metal counterparts when irradiated with light, due to their differences in absorption, scattering, and reflective properties. Myriad colors can be obtained by varying the metal used, size, and shape of the nanostructures. Creating a multi-colored image using nanoplasmonic structures over large areas however presents a unique set of challenges. As the size and the distance between the particles can both affect the final color observed, it is important to be able to pattern individual structures at specific positions in order to make up the various colors to create an image. Self-assembly techniques that can coat large areas of substrate quickly and effectively are currently not capable of providing control over both size and position of the nanostructures. The remaining options lie in the use of lithographic technologies for the production of color images over small and medium scales while imprinting technologies will potentially allow large scale images to be achieved.

The use of plasmonic nanostructures to produce color microimages has been previously explored by several research groups such as in the generation of holographic images [1] and full RGB color filters [2]. However, these images require specific lighting conditions for viewing, e.g. by grazing-angle or back-illumination setups. In most applications it would be ideal to view these images in reflected brightfield mode, which is the most natural way of viewing. In this study, we demonstrate how it is possible to shrink color photographs/images to the microscale by exploiting the nanoplasmonic effect.[3] We patterned our nanostructures using electron-beam lithography and subsequently deposited thin layers of silver (15 nm) and gold (5 nm) on the structures to give the structures color. Due to the technique used, it is possible to create color pixels that are an order of magnitude smaller than those created by today's highest-resolution printers. The color achieved is also conveniently tuned by changing the lateral dimensions of the structures. Figure 1 shows an example of the structures obtainable by this method. The unique feature of our structures with respect to other similar plasmonic structures is the fact that these may be viewed in regular lighting conditions, without the need for expensive optics, much like the viewing of a photograph. Numerical simulations of these structures agree well with experimental observations. These simulations enable the programming of structural color using nanoplasmonic structures, which could also be useful as a method to create anti-counterfeit security tags using complex images.

References
[1] Ozaki M. et al., Science 2011, 332, 218
[2] Inoue D. et al., APL 2011, 093113
[3] Singaporean patent application 201105529-9, priority date 12.09.2011

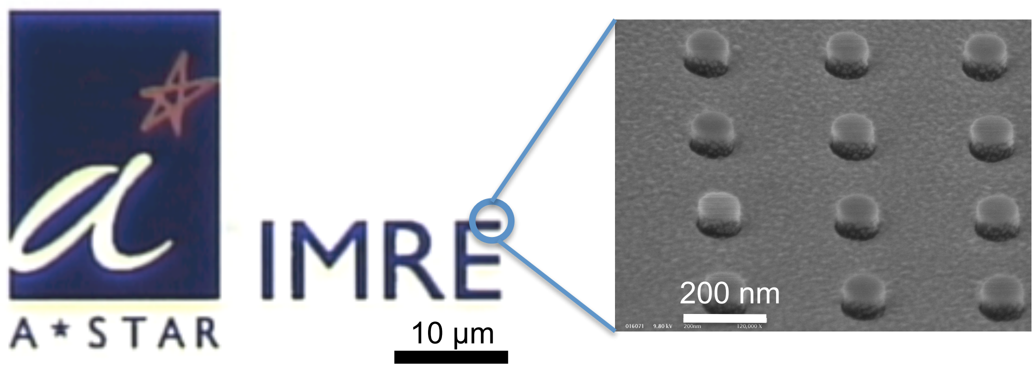

Figure 1: Color Microphotograph. The image on the left was obtained using brightfield reflection microscopy. The colors observed are due to the localized surface plasmon resonances of the metalized nanopillars. The SEM image on the right shows the mignified side view of the pillars used to make up the microphotograph.