Moving Towards Structural Color Display: Angle Insensitive Structural Colors Based on Metallic Gratings and Color Pixels beyond the Diffraction Limit

Cheng Zhang[1], Yi-Kuei Ryan Wu [1], Andrew E. Hollowell[1, 2] and L. Jay Guo[1]

[1]*Department of Electrical Engineering and Computer Science, C-PHOM,*
The University of Michigan, Ann Arbor, Michigan 48109, USA
[2]*Sandia National Laboratories, Albuquerque, NM 87123, USA*

Current display technologies employ colorant pigments which are vulnerable to a variety of processing chemicals, cannot withstand constant strong light illumination and require multistep processing to pattern individual pixels. An attractive alternative to colorant pigments is structural colors based on plasmonic nanostructures, in which the surface plasmon polaritons are excited via grating coupling. High efficiency has been achieved using this technique; however it possesses inherent angle dependence. For practical display applications, this angle dependent spectrum should be overcome. In our work, we have theoretically and experimentally studied a vertical nanocavity for highly efficient, angle robust color filtering. Moreover, this structure has demonstrated color pixel size beyond the diffraction limit and wide color tunability throughout the entire visible spectrum.

A schematic diagram of this plasmonic cavity array is illustrated in figure 1(a) as well as an SEM image of a fabricated device. Silver is conformally sputtered onto a fused silica grating denoted by the pitch (P), depth (D) and width (W). In contrast to trapping the incident light into grating assisted surface plasmon (GASP) mode, the structure is specifically designed to concentrate light into the metal insulator metal Fabry Perot (MIMFP) mode in the nano grooves based on the light funneling effect [1], as shown in figure 1(b). This selective excitation of the MIMFP modes instead of the GASP modes ensures angle robustness, which is verified by the experimental results shown in figure 1(c). The resonance wavelength is dependent on both the groove width W and depth D [2], which provides a flexible design rule for the color filters.

As a vivid demonstration of the visual performance of these color filters, we have designed and fabricated colored images in the format of the Olympic Rings. Figure 2 is a direct microscope picture of the device under 100X and the corresponding SEM image. Note that the purple color from the rope held by the gymnast in the top middle ring is produced by two nano grooves, each of which is only 60nm in width. This color demonstration proves that the proposed plasmonic structural color is capable of creating pixels with sizes beyond the diffraction limit of light. What's more, we have verified that even a single slit has the color filtering effect as well. One merit of such a capability is super pixel imaging [3], in which different color pixels could be arranged close to each other and color mixing can be obtained with superior resolution. Therefore, "beyond diffraction limit" color pixel adds another degree of freedom for people to tune color across the full spectrum.

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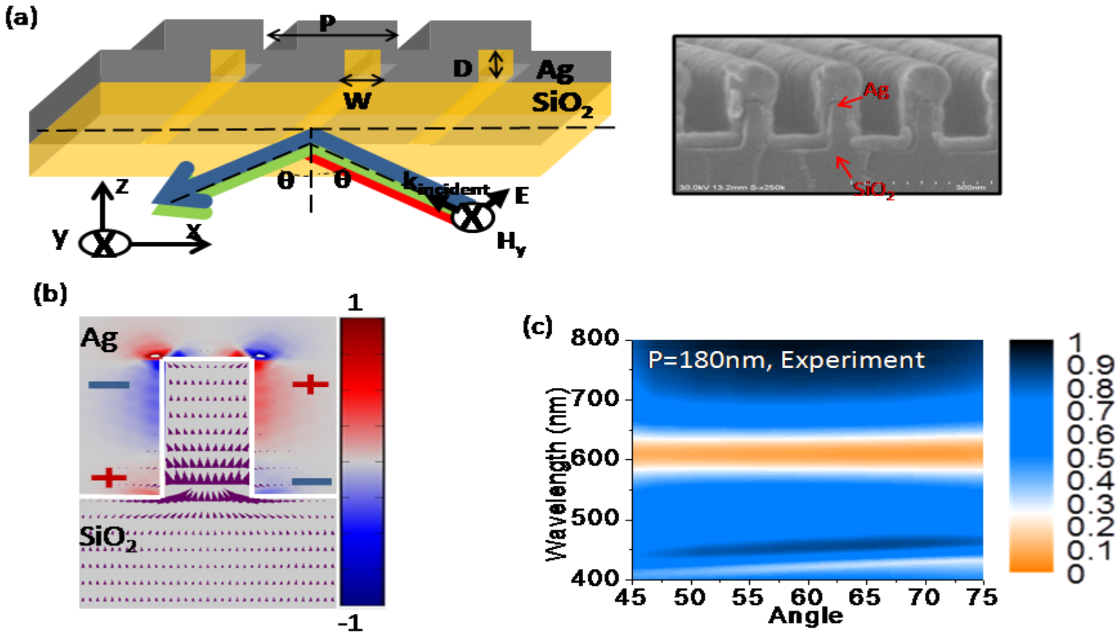

Figure 1: Plasmonic-nanocavity-based angle robust color filtering. (a) A schematic of the proposed structure and corresponding SEM image of a fabricated device. (b) Polarization charge and Poynting vector distribution of light funneled into these nano grooves, presented with the red–blue surface plot and purple arrows, respectively. (c) The angle resolved measured reflection spectra with the following device dimension P=180, W=50, and D=130nm.

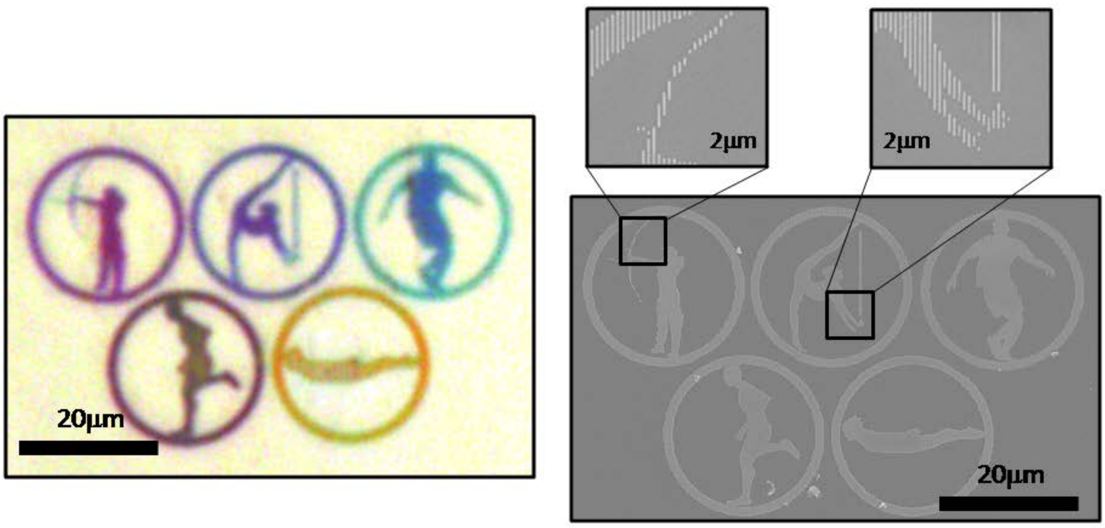

Figure 2: Vivid color demonstration and colored pixel size beyond the diffraction limit: Color demonstration with ultra-high resolution Olympic ring image and its SEM image. The full range of CMY colors are achieved by sweeping W from 40 to 90nm, with P and D fixed at 180nm and 170nm respectively. Note that the purple color from the rope held by the gymnast in the top middle ring is produced by two nano grooves, each of which is only 60nm in width. The image looks blurred because the sizes of pixels go beyond the diffraction limit.