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PhD title: Gap-surface plasmon based metasurfaces for nano-optics applications

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Nanostructures are at least 1000 times smaller than the small things that our eyes can see, for example human hair. By using these nanostructures in thin 2D planar configuration, one can achieve thin metasurfaces. The term 'meta' implies that such tiny structures can perform mighty tasks, which are beyond the capabilities of ordinary materials. In my research, I have used metasurfaces for light-based applications. The devices made from metasurfaces span light deflection at desired angle and efficiency, focusing, and color printing. All these devices can be designed and fabricated with nanoscale precision using advanced fabrication techniques like the electron beam lithography, which can have a spot size focused down to few nanometers for writing of tiny structures on a polymer mask. Typically, the visible light is within 450 to 750 nm, which makes these structures subwavelength in size for precise control.

While many metasurfaces have been realized in the scientific community, my research is based on reflective type metasurfaces made of thin metal-dielectric-metal films. The dielectric layer sandwiched between metals is few 10s of nanometers, which allows incident light to be confined in such a small gap. The coupled oscillations of top layer of thin metallic nanostructures, and bottom bulk layer of metal support standing wave type resonances called gap-surface plasmon (GSP) resonances for electric and magnetic fields. Each structure in a periodic array can be used to manipulate light in the smallest scale possible to fabricate using the latest technology. The resonances can be scaled to first-order and higher-order by accordingly scaling the geometrical size of the nanostructures. In my study, the unique features of the third-order based GSP metasurfaces have been explored.

The metasurfaces allow the regular bulk optical devices to be transformed completely to realize nano-optics devices. This is a remarkable feat as the diffracted light of different colors/wavelengths can be seen with our eyes, but the structures that brought about the diffraction cannot as they are ultrathin. While a bulk lens can focus sunlight down to visible spot of high intensity to burn materials, the metasurface lens is ultrathin to achieve a much precise spot. For color printing application, the metasurfaces can generate color images in an area of the order of 2-10 micrometers. The third-order GSP based metasurfaces allow for all these exciting metasurface-based applications with certain key advantages. The third-order GSP resonance allows for a unit cell size that is larger with approximately less than 1.5 times the visible light wavelength. In comparison, the first-order GSP resonance has size 2.5 times smaller than the visible wavelength. Thus, the yield of fabricating the metasurfaces is significantly improved by using third-order GSP resonances. This is highly beneficial for large-scale manufacturing of the metasurfaces as it can provide relaxed constraints on fabrication with quick and economical solutions. The next feature is the dual-bandwidth operation, which is supported by both first-order and third-order GSP resonance based on the physics of the GSP unit-configuration. Lastly, a flexible advantage of the GSP-based metasurface is explored, where the three-layer configuration can be controlled by changing the metallic layers with different types of binary metal combinations.

The features of GSP-based metasurfaces are rare to find in other types of metasurfaces, which makes the GSP configuration a smart option for metasurfaces. In my PhD, I have demonstrated these advancements through proof-of-principle applications of metasurfaces for nano-optics devices.