Self assembled glass and liquid-plasmonic metasurface via controlled fluid instability

Tapajyoti Das Gupta [(1)], Renu Raman Sahu [(1)], Alwar Samy R, Aravind Yellashetty[(2)]
(1) Indian Institute of Science Bangalore, e-mail: tapajyoti@iisc.ac.in

Modern devices require the tuning of the size, shape, and spatial arrangement of nano-objects and their assemblies with nanometer scale precision, over large-area and sometimes soft substrates. Such stringent multi-scale and mechanical requirements are beyond the reach of conventional lithography techniques or simpler self-assembly approaches. In this talk, at first, we will demonstrate an unprecedented control over the fluid instabilities of thin glass films as a simple approach for the self-assembly of advanced all-dielectric metasurfaces. We show and model via fluid mechanics the tailoring of the position, shape, size and inter-particle distance of nano-objects with feature sizes below ten nanometers. This simple and versatile approach can generate optical nanostructures over tens-of-centimeters sized rigid and soft substrates, with better optical performance and a resolution on par with advanced lithography-based processes. By a programmable control of the nanoimprinting method and the initial film thickness we show that we can achieve tunable particle size and lattice using the same master Silicon mold. To underline the potential of our approach, we demonstrate various optical phenomenon. Our ability to fabricate the metasurfaces on stretchable substrates without undergoing any lift off process finds application in mechano-chromic sensors. The ability to fabricate quasi 3D structures find application in phase tunable metasurfaces. Lastly, by having an unprecedented control over the lattice and particle size we demonstrate sharp Fano resonances with the highest Quality factor ~300 in the visible to date. Such resonances are exploited to realize high efficiency protein monolayer detection and to generate strong Second harmonic generation highlighting the unprecedented reconciliation between state-of-the-art optical performance and simple self-assembly fabrication approaches.

In the second part, for the first time we will show a single-step procedure that exploits the fluid instabilities of liquid metal on soft PDMS substrate, tending to minimize surface energy by forming spherical droplets of sizes in sub-optical length scales. By tuning the softness of the substrate, the temperature of the substrate during deposition, the rate of deposition, and the thickness of the liquid metal, we demonstrate a fabrication technique of gallium-based plasmonic thin film with tuneable structural colors for the first time, paving the way toward a novel paradigm in soft photonics and large area reflective displays. By tuning and optimizing a range of experimental parameters, and the choice of substrate material we obtain vibrant coloration encompassing a wide range of chromaticity coordinates as a result of the controlled Ga nanodroplets. Analysis of scanning electron microscope images for structural characterization of the samples fabricated by our methodology emphasizes the importance of liquid oligomers in the heat-cured Poly-dimethyl siloxane in the formation of non-overlapping Gallium nanodroplets, which is not the case when the oligomers are deliberately removed by toluene treatment. In the latter case, the absence of oligomers results in the formation of nanodroplets without penetration into the substrate, forming a film of nanodrops akin with reflective properties akin to a thin film over a substrate. Similar is the case with SEBS as a substrate, which also shows specular broadband reflection owing to the formation of a thin film of Ga unpenetrated nanodroplets over the surface substrate.
As a proof-of-principle, we show pallets of structural colors of the films derived from this process. Reflective display technology can be a majorly benefitted by leveraging the advantages of structural colors over its pigmented counterparts. The application of the thus-fabricated device exhibits mechanochromic sensing, which has been characterized to be of high fidelity and reliability, functionalized by exploiting the fluidic properties of Gallium. For at least 1000 cycles of uniaxial stretching and relaxing with a periodicity of 50 seconds, the reflectivity spectrum of the sample for a given strain was unchanged, thus proving the reliable reconfiguration of sample response to the application and removal of mechanical strain. The reversible change in the reflectivity spectrum results in the chromaticity coordinates of the sample, hence a visible change in the sample color. Our results have the potential to offer opportunities to dynamically reconfigure thin-film-based functional nanodevices in situ as well as process technology for high throughput fabrication to achieve the same in a single-step method.

1. T. Das Gupta et al. “Self-assembly of nanostructured glass metasurfaces via templated fluid instabilities”; Nature Nanotechnology: 14, 2019., pp 320-327, doi: 10.1038/s41565-019-0362-9

2. T. Das Gupta et al. “Second harmonic generation in glass-based metasurfaces using tailored surface lattice resonances,” Nanophotonics, 10 (13), 2021., pp 3465-3475, doi: 10.1515/nanoph-2021-0277