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► To cite this version:

Adrian Agreda, Tong Wu, Adrian Hereu, Romain Pacanowski, Arthur Dufay, et al.. Control of visual appearance with disordered plasmonic resonant metasurfaces. SPP 2023 - The International Conference on Surface Plasmon Photonics 10, May 2023, Houston, TX., United States. <hal-04177866>

HAL Id: hal-04177866

<https://hal.science/hal-04177866v1>

Submitted on 6 Aug 2023

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Control of visual appearance with disordered plasmonic resonant metasurfaces

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A longstanding and fundamental ambition of waves science is the achievement of materials with prescribed optical properties and targeted far-field responses [1]. Notably, light manipulation by means of micro- and nanostructured metasurfaces [2] has found fertile ground in the control and generation of colors [3] and, most recently, unusual visual appearance [4]. Be they disordered as in Fig. 1a, or precisely organized, metasurfaces composed of arrays of Mie, plasmonic or Fabry-Perot nanoresonators offer several degrees of freedom for engineering visual appearance design. Curiously, most of the attention has gone to overall chromatic properties and many important aspects that determine the integral visual appearance of a surface have been largely ignored.

Quantitatively retrieving the visual appearance of metasurfaces requires advanced knowledge of the nanoscale resonances, mesoscale interferences and macroscale light transport defining the bidirectional reflectance distribution function (BRDF, Fig. 1a). This problem is inherently multidimensional and complex; hence brute-force full-wave electromagnetic analysis is not viable.

In this context, we present an interpretive, intuitive and accurate modal-based tool that unveils the main physical mechanisms impacting the color and visual appearance of complex metasurfaces [5]. We implement, test, and validate our tool for disordered colloidal monolayers of plasmonic silver nanoparticles deposited on a reflective substrate coated with a submicrometric dielectric spacer (Fig. 1a). Our approach successfully predicts and intuitively explains that metasurfaces combining plasmonic and Fabry-Perot resonances offer uncommon iridescent visual appearance not observed with natural nanostructures or thin-film interferences (Fig. 1b-c). The model also clarifies the remarkable resilience of the iridescent metasurfaces to size and shape polydispersity of the plasmonic nanoresonators. Fabrication flexibility is essential for real applications of plasmonic metasurfaces, as it may result in a strong reduction of manufacturing costs for large-scale coatings production.

We expect this work to inspire and motivate further metasurface designs exhibiting complex visual appearances that are traditionally difficult to predict and assess.

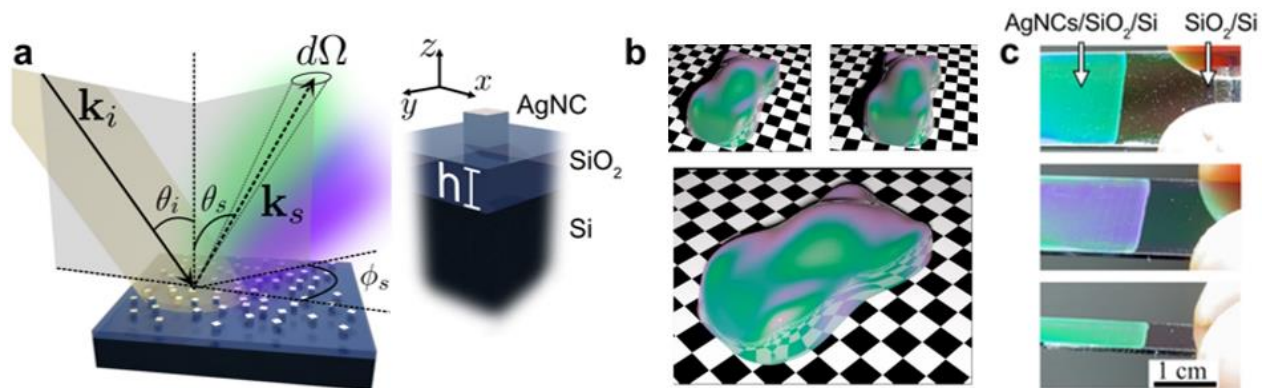


Fig. 1. **a**, BRDF definition schematic. The samples consist of disordered arrays of ~ 100 nm side silver nanocubes (AgNCs) on silicon substrates, coated with a thin SiO_2 layer of height h . **b**, Rendered images of a macroscopic speedshape covered by silver nanospheres on a SiO_2/Si substrate for $h = 600$ nm. **c**, Fabricated two-color iridescent metasurface under sunlight illumination for various viewing θ_s and lighting θ_i directions.

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