

# Large scale metasurfaces: from plasmonics to photon harvesting in 2D semiconductor layers

Maria Caterina Giordano<sup>1\*</sup>, Matteo Gardella<sup>1</sup>, Matteo Barelli<sup>1</sup>, Giorgio Zambito<sup>1</sup>, Giulio Ferrando<sup>1</sup>, Pham Duy Long<sup>2</sup>, Nguyen Si Hieu<sup>2</sup>, Francesco Buatier de Mongeot<sup>1</sup>

<sup>1</sup> Dipartimento di Fisica, Università di Genova, I-16146 Genova, Italy

<sup>2</sup>Institute of Materials Science, Vietnam Academy of Science and Technology, Hanoi, Vietnam

\*corresponding author, E-mail: giordano@fisica.unige.it

## Abstract

The nanofabrication of large-area optical metasurfaces with tunable optoelectronic response is crucial in many fields ranging from plasmonics to energy conversion. Here the engineering of self-organized plasmonic nanostructure antennas will be demonstrated, showing their performances in photo-degradation of polluting molecules. In parallel, the capability to strongly couple light to large area (cm<sup>2</sup> scale) ultra-thin semiconductor layers will be shown. Thanks to nanoscale re-shaping of the interface to form flat-optics nanogratings superior photon harvesting performances can be achieved with strong impact in photonics and energy conversion.

## 1. Introduction

The engineering of metasurfaces based either on plasmonic nanoantennas or on atomic two-dimensional (2D) materials is currently a very active field of research with a strong impact in optoelectronics, sensing, and nanophotonics [1,2]. A recent trend in the field aims to increase the complexity of lithographically designed metasurfaces for sensing and optical spectroscopies to photo-conversion. However, in order to scale-up these promising configurations to real-world devices and applications, alternative large-area approaches are attracting an increasing attention. Here we demonstrate the engineering of large-scale metasurfaces based on self-organized plasmonic nanoantennas [3,4]. The plasmonic response of self-organized arrays of nanoantennas is tuned in order to boost the photo-degradation of polluting molecules in solution, with strong impact in photochemistry [5]. Within a parallel research line, large-scale flat-optics MoS<sub>2</sub> nanogratings are developed demonstrating broadband photon harvesting [6,7] with strong impact in new-generation photonic and energy conversion devices.

## 2. Results and discussion

Self-organized plasmonic metasurfaces are fabricated with a novel large area (cm<sup>2</sup>) approach exploiting the ion beam induced wrinkling in glass substrates for the synthesis of transparent faceted nanopatterns [1]. These templates are ideal for the maskless confinement of quasi-one

dimensional (1D) arrays of plasmonic nanostripes (Fig. 1). Controlled tuning of localized plasmon resonances from the visible to the Near- and Mid-IR can be achieved by tailoring nanoantennas shape and/or light polarization, thus demonstrating competitive sensing performances in SEIRA [2], SERS [3], and plasmonic color routing [4]. Very recently, the plasmon-enhanced photobleaching of dye molecules has been shown, thus opening new avenues in photochemistry and energy storage [5].

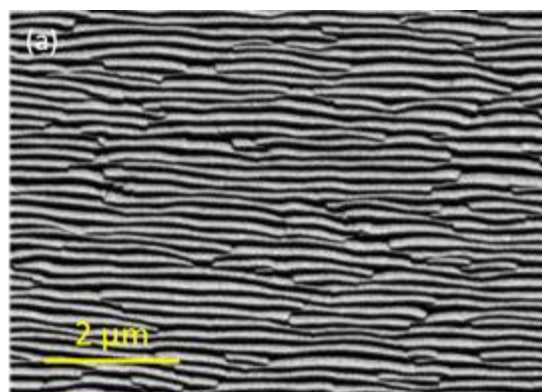


Figure 1 Self-organized plasmonic nanostripe arrays (top-view SEM image).

## 3. Conclusions

In conclusion, we demonstrated the self-organized engineering of anisotropic arrays of plasmonic nanoantennas supporting tunable plasmonic response and near-field enhancement for sensing. We have shown the possibility to engineer plasmonic antennas featuring plasmon enhanced photobleaching, paving the way for color routing in novel large-scale flat-optics components.

## Acknowledgements

M.C. Giordano, F. Buatier de Mongeot and, P. D. Long acknowledge support from MAECI within the bilateral Italy – Vietnam project, Progetti di Grande Rilevanza 2021-2023 and from Università di Genova within BIPE 2020 project.

## References

- [1] M.C. Giordano, F. Buatier de Mongeot, Anisotropic Nanoscale Wrinkling in Solid State Substrates. *Adv. Mater.* 30.30, 1801840, 2018.
- [2] M.C. Giordano et al. Self-Organized Nanorod Arrays for Large-Area Surface-Enhanced Infrared Absorption. *ACS Appl. Mater. Interf.* 12(9), 11155, 2020.
- [3] M. Barelli, et al. "Self-organized nanogratings for large-area surface plasmon polariton excitation and surface-enhanced Raman spectroscopy sensing." *ACS Applied Nano Materials* 3 (9) , 8784, 2020.
- [4] M. Barelli et al. Color Routing via Cross-Polarized Detuned Plasmonic Nanoantennas in Large-Area Metasurfaces. *Nano Lett.*, 20(6), 4121, 2020.
- [5] M. Barelli et al. Wavelength-Dependent Plasmonic Photobleaching of Dye Molecules by Large-Area Au Nanostripe Arrays, Under review
- [6] C. Bhatnagar et al., Ultra-broadband photon harvesting in large-area few-layer MoS<sub>2</sub> nanostripe gratings. *Nanoscale* 12(48), 24385, 2020.
- [7] C. Bhatnagar et al., Tunable Light Harvesting in Nanorippled MoS<sub>2</sub> Ultrathin Films." *ACS applied materials & interfaces* 13 (11) 13508, 2021.