

# Plasmonic nanoantennas and their applications

Pierre Berini

School of Electrical Engineering and Computer Science, University of Ottawa, Ottawa, Canada  
 Department of Physics, University of Ottawa, Ottawa, Canada  
 Centre for Research in Photonics, University of Ottawa, Ottawa, Canada  
 \*corresponding author, E-mail: berini@eecs.uottawa.ca

## Abstract

We review recent work on plasmonic nanoantennas and their applications in nonlinear optics and in optoelectronics.

## 1. Introduction

Nanometallic structures, such as resonant plasmonic nanoantennas, are essential to the conversion of light to surface plasmon-polaritons (SPPs) localized to ultra-small volumes [1]. Such structures can provide highly enhanced fields, strong confinement, high surface sensitivity, and can double as a device electrode for applying voltages or passing currents to active regions in optoelectronic devices. Here we review some of their many applications, in the areas of plasmon-enhanced nonlinear optics [2-5] and optoelectronics [6-9].

## 2. Applications in nonlinear optics

In nonlinear optics, plasmon enhancement can be applied to the pump [2], or to the nonlinear emission [3-5], through spectral alignment. An advantage of the former is that all nonlinear processes involving the pump are enhanced, but a disadvantage is that the pump, typically of high intensity, can damage the nanostructures. Nonetheless, such enhancement was exploited in high-harmonic generation via re-collision radiation in Si [2], where a 10× enhancement was observed for all harmonics emitted up to the 9<sup>th</sup>.

Alternatively, applying plasmon enhancement to the nonlinear emission by designing them to be resonant with the emission is advantageous because the latter is typically weak, and the structures are non-resonant with the pump so are less susceptible to damage. Such enhancement was exploited in Raman scattering experiments [3-5], where the nanoantennas were spectrally-aligned with the Stokes wavelengths of graphene. Under this scenario, single-antenna scattering cross-section enhancements of over 500× were observed [5].

## 3. Applications to optoelectronics

In optoelectronics, plasmon enhancement can be exploited to improve the performance of, *e.g.*, electro-optic modulators [6], photodetectors [7], and beam-steering

devices [8-10]. A key requirement is for the plasmonic enhancement to overlap strongly with the active region of the device, which requires that the nanostructure also operate as a device electrode. Fig. 1 shows such a structure, consisting of an array of Au nanoantennas contacted perpendicularly by electrical contact lines. The contact lines are centred on the nanoantennas (dipoles), which ensures that they are minimally invasive optically, due to their orthogonal alignment relative to the incident polarisation which is along the nanoantenna axes. Structures such as these are very promising for beam steering, as each row can be routed to an individual contact such that a 1D phase gradient is applied over the array [8]. Nanostructures that consist of holes in a metal film are also of significant interest, especially arrangements of nanoholes (*e.g.*, heptamers), which can be fabricated via focussed ion beam milling because they exhibit interesting and useful Fano resonances [11, 12].

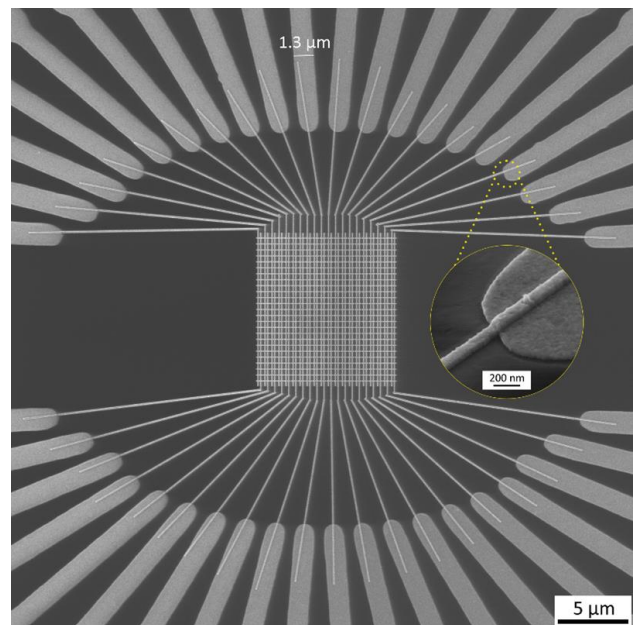


Figure 1: HIM image demonstrating overlay alignment of a  $10 \times 10 \mu\text{m}^2$  gold nanoantenna array and its connection to 40 gold fingers on a pre-existing fan-out microstructure. Inset: Magnified image acquired at a tilt angle of  $54^\circ$  reveals step-height coverage of a fan-out finger by a nanoscale connector. The structures were fabricated on a fused silica substrate.

## 4. Conclusions

Resonant plasmonic nanoantennas are useful for the conversion of light to SPPs localized to ultra-small volumes. They provide highly enhanced fields, strong confinement, high surface sensitivity, and can double as a device electrode for applying voltages or passing currents to active regions in optoelectronic devices.

## References

- [1] Bharadwaj, P., Deutsch, B., Novotny, L., *Adv. Opt. Photonics* 1, 438-483, 2009
- [2] Vampa, G., Ghamsari, B. G., Siadat Mousavi, S., Hammond, T. J., Olivieri, A., Lisicka-Skrzek, E., Naumov, A., Villeneuve, D. M., Staudte, A., Berini, P., Corkum, P. B., *Nature Physics* 13, 659, 2017
- [3] Ghamsari, B. G., Olivieri, A., Variola, F., Berini, P., *Nanophotonics* 3, 363, 2014
- [4] Ghamsari, B. G., Olivieri, A., Variola, F., Berini, P., *Phys. Rev. B* 91, 201408, 2015
- [5] Al-Shehab, M., Ghamsari, B. G., Berini, P., *J. Opt. Soc. Am. B*, 36, F49, 2019
- [6] Olivieri, A., Chen, C., Hassan, S., Lisicka-Skrzek, E., Tait, R. N., Berini, P., *Nano Letters* 15, 2304-2311, 2015
- [7] Alavirad, M., Olivieri, A., Roy, L., Berini, P., *Optics Express* 24, 22544-22554, 2016
- [8] Calà Lesina, A., Goodwill, D., Bernier, E., Ramunno, L., Berini, P., *IEEE J Sel. Top. Quant. Electr.* 27, 4700116, 2021
- [9] Calà Lesina, A., Goodwill, D., Bernier, E., Ramunno, L., Berini, P., *Optics Exp.* 28, 31637, 2020
- [10] Rashid, S., Walia, J., Northfield, H., Hahn, C., Olivieri, A., Calà Lesina, A., Variola, F., Weck, A., Ramunno, L., Berini, P., *Nano Futures* 5, 025003, 2021
- [11] Hahn, C., Hajebifard, A., Berini, P., *Nanophotonics* 9, 393-399, 2020
- [12] Hajebifard, A., Hahn, C., Walia, J., Suleman, H., Variola, F., Weck, A., Berini, P., *J. Appl. Phys.* 129, 033103, 2021