Unconventional plasmonic architectures: electric and magnetic field manipulation for ultrasensitive infrared spectroscopy

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Complex 3D plasmonic nanostructures represent a unique tool for accessing the physical, structural and chemical properties of matter in a multidisciplinary context, ranging from physics to chemistry and from biology to medicine. In particular, improving the sensitivity of infrared spectroscopy is a longstanding challenge that promises to have a great impact on fundamental studies involving the interaction of such long wavelengths with nanostructured materials (*e.g.* quantum dots, nanorods, nanotubes etc.) as well as biomolecules at extremely low concentrations [1-3].
Here we would like to introduce novel lithographic methods, able to produce multipurpose "free-standing" nanostructures/nanocavities, made of noble metals and endowed with various shapes and spatial arrangements (see Figure 1). The proposed architectures can offer new and unconventional properties such as the realization of high electric field confinement and enhancement, broad-band optical absorption, strong radial scattering and well defined radiation pattern [4-6]. Moreover, the unique properties of these plasmonic nanostructures can be exploited to improve the vibrational signal enhancement in antenna-assisted surface-enhanced infrared spectroscopy (SEIRS and NETS) induced by electric hot-spot generation [6-8].
Concurrently, the optical manipulation of magnetic properties in nanostructured materials [9-10] is a very promising research field with several implications in data storage and ultrasensitive detection. Recently, in the field of metamaterials, split-ring architectures have been proposed for the excitation of spectrally narrow magnetic resonances in the THz range [11]. However, the geometry of these devices strongly limits the field localization to the size of the ring structure. Within this context, we developed and experimentally demonstrated a plasmonic nanoarchitecture able to sustain a magnetic *coil-type* plasmonic mode induced in Fano resonance condition. The proposed configuration compensates the ohmic losses with the intense displacement current triggered inside small interparticle gaps. Furthermore, the plasmonic nature of these resonances induces the sub-wavelength concentration/generation of magnetic hot-spots at optical frequencies [12-13].

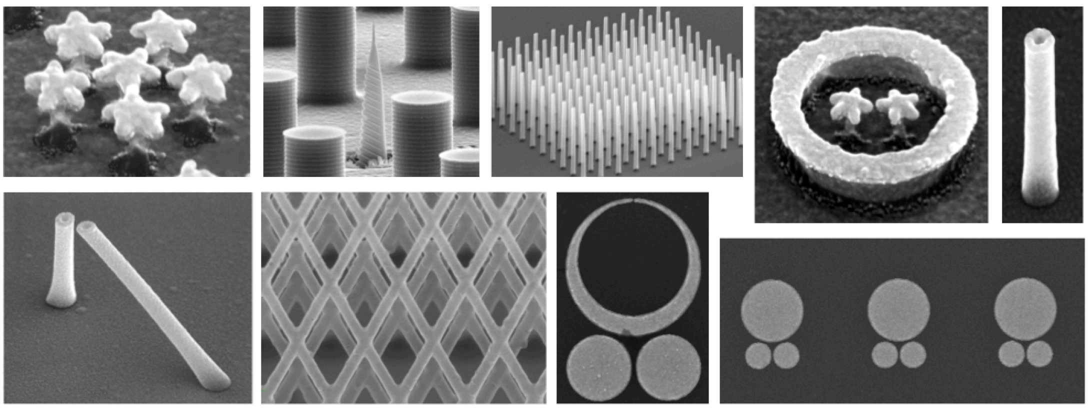

Figure 1. Representative SEM micrographs of 3D plasmonic nanodevices and planar Fano coil-type resonators.

1. C. D'Andrea, J. Bochterle, A. Toma, C. Huck, F. Neubrech, E. Messina, B. Fazio, O. M. Maragò, E. Di Fabrizio, M. Lamy de la Chapelle, P. G. Gucciardi, A. Pucci, **ACS Nano 7** (2013) 3522.
2. C. Huck, F. Neubrech, J. Vogt, A. Toma, D. Gerbert, J. Katzmann, T. Härtling, A. Pucci, **ACS Nano 8** (2014) 4908.
3. H.-R. Park, K. J. Ahn, S. Han, Y.-M. Bahk, N. Park, D.-S. Kim, **Nano Lett. 13** (2013) 1782.
4. F. De Angelis, M. Malerba, M. Patrini, E. Miele, G. Das, A. Toma, R. Proietti Zaccaria, E. Di Fabrizio, **Nano Lett. 13**, 3553 (2013).
5. P. Zilio, M. Malerba, A. Toma, R. Proietti Zaccaria, A. Jacassi, F. De Angelis, **Nano Lett. 15**, 5200 (2015).
6. M. Malerba, A. Alabastri, E. Miele, P. Zilio, M. Patrini, D. Bajoni, G. C. Messina, M. Dipalo, A. Toma, R. Proietti Zaccaria, F. De Angelis, **Scientific Reports 5** (2015) 16436.
7. C. Huck, A. Toma, F. Neubrech, M. Chirumamilla, J. Vogt, F. De Angelis, A. Pucci, **ACS Photonics 2** (2015) 497.
8. A. Toma, S. Tuccio, M. Prato, F. De Donato, A. Perucchi, P. Di Pietro, S. Marras, C. Liberale, R. Proietti Zaccaria, F. De Angelis, L. Manna, S. Lupi, E. Di Fabrizio, L. Razzari, **Nano Lett. 15** (2015) 386.
9. T. Kampfrath, M. Battiato, P. Maldonado, G. Eilers, J. Notzold, S. Mahrlein, V. Zbarsky, F. Freimuth, Y. Mokrousov, S. Blugel, M.Wolf, I. Radu, P. M. Oppeneer, M. Munzenberg, **Nat. Nanotechnol. 8,** (2013) 256.
10. F. Shafiei, F. Monticone, K. Q. Le, X.-X. Liu, T. Hartsfield, A. Alù, X. Li, **Nat. Nanotechnol. 8**, (2013) 95.
11. T. J. Yen, W. J. Padilla, N. Fang, D. C. Vier, D. R. Smith, J. B. Pendry, D. N. Basov, X. Zhang, **Science 303**, (2004) 1494.
12. A. Nazir, S. Panaro, R. Proietti Zaccaria, C. Liberale, F. De Angelis, A. Toma, **Nano Lett. 14**, (2014) 3166.
13. S. Panaro, A. Nazir, R. Proietti Zaccaria, L. Razzari, C. Liberale, F. De Angelis, A. Toma, **Nano Lett. 15**, (2015) 5200.