Enhanced picosecond acoustic response near the surface plasmon resonance of Ni/Au-nanoparticles metastructures.

O. Y. Kovalenko*, Y. Liu, J.-W. Kim, G. Versini, and J.-Y. Bigot
Institut de Physique et Chimie des Matériaux de Strasbourg, UMR 7504, CNRS, Université de Strasbourg, BP 43, 23 rue du Loess, 67034 Strasbourg, France
*corresponding author: oleksandr.kovalenko@ipcms.unistra.fr

Abstract-In this work we consider the interaction between picosecond acoustic pulses generated in a 300 nm thick Ni film and the localized Surface Plasmons of Au nanoparticles. The monolayer of gold nanoparticles, self-organized on top of the Ni film, allows us detecting the acoustic signal as a function of wavelength near their surface plasmon resonance. Near resonance, an amplification factor of 55 is measured as compared to the bare Ni film. Our approach precludes useful applications in opto-acoustics and magneto-acoustics.

The generation of picosecond acoustic pulses in metals, using femtosecond optical pulses, is a well-known process [1] which has found several applications for example in acousto-optics, electro-acoustics or magneto-acoustics [2-4]. On the other hand, plasmonic structures efficiently enhance the transmission of light through subwavelength arrays of holes, near the surface plasmon resonances (SPR) of the meta-structure [5]. This effect is useful as well for applications in biology, chemistry and medicine [6]. From a dynamical point of view, the time dependent optical properties near the SPR of noble metal nanoparticles [7] or arrays of holes [8] result from the interplay between the real and imaginary parts of the metal dielectric function, involving mostly the Coulomb interaction, the electron-lattice interaction and the thermal diffusion to the surrounding medium. Here we consider picosecond acoustic pulses propagating in a meta-structure made of a Ni-film on top of which a single layer of self-organized Au nanoparticles is deposited. The study of the time dependent acousto-optic spectral response reveals a factor of amplification larger than 55 near the SPR as compared to the bare Ni film.
The metastructure consists of: a sapphire substrate, a 300 nm-thick Ni layer and a monolayer of self-organized Au nanoparticles with 10 nm diameter deposited on it [9]. The strong dipolar interaction between the self-organized nanoparticles induces a red shift of the SPR to 680 nm (inset (1a) of Fig. 1) as compared to the individual nanoparticles (SPR at 526 nm). The acoustic pulses are generated at the Ni surface exciting through the Al_2O_3 substrate with femtosecond laser pulses with 4.4 mJ/cm^{-2} energy density. Part of the metastructure is not covered with nanoparticles, so that the acoustic pulses can be monitored (inset (1b) of Fig. 1). After propagation through the Ni film, the acoustic pulses interact with the gold nanoparticles which time dependent reflectivity, as shown in Fig.1, is probed on the opposite side of the structure (nanoparticles side) with white light continuum pulses generated in a sapphire plate. Various wavelengths can be selected with a slit put in a prism compression line after the supercontinuum generation. The inset (1c) of Fig. 1 displays the spectral variation of an enhancement of the acousto-optic induced reflectivity. A factor 55 is obtained near resonance showing the interaction of the acoustic pulses with the surface plasmons.

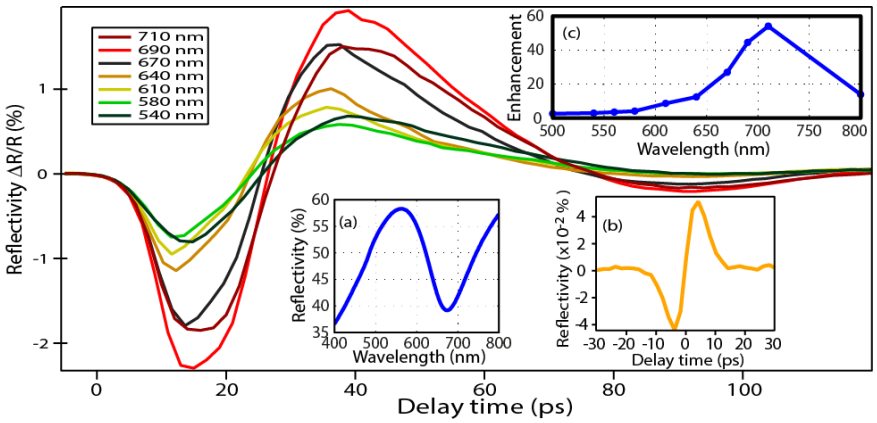

Figure 1. Spectro-temporal reflectivity of Au nanoparticles excited by picosecond acoustic pulses. Insert (a): static reflectivity spectrum showing the SPR, (b): temporal shape of the exciting acoustic pulse, (c): amplification of acousto-optic response at the SPR.

Our results show that the use of self-organized Au nanoparticles as ultrashort acoustic pulse detector is a way to improve the sensitivity of ultrasonics sensors which can be used for example in the acoustic microscopy.

Acknowledgements, The authors thank the European Research Council for financial support via the ERC Grant "ATOMAG" ERC-2009-AdG-20090325#247452 and the LaBex "Nanoparticles Interacting with their Environment" ANR-11-LABX-0058_NIE.

REFERENCES

1. Thomsen, C., Grahn, H. T., Maris, H. J. and Tauc, J., "Surface generation and detection of photons by picosecond light pulses," *Phys. Rev. B*, Vol. 34, No. 6, 12080–12088, 1986.
2. Keller, U., Li, K. D., Khuri-Yakub, B. T., Bloom, D. M., Weingarten, K. J. and Gerstenberger, D. C., "High-frequency acousto-optic mode locker for picosecond pulse generation," *Opt. Lett.* Vol. 15, No. 1, 45-47, 1990.
3. Lin, K.-H., Yu, C.-T., Wen, Y.-C. and Sun, C.-K.., "Generation of picosecond acoustic pulses using a p-n junction with piezoelectric effects," *Appl. Phys. Lett.*, 86, 093110, 2005.
4. Kim, J., Vomir, M., and Bigot, J.-Y., "Ultrafast Magnetoacoustics in Nickel Films," *Phys. Rev. Lett.*, 109, 166601, 2012.
5. Ebbesen, T. W., Lezec, H. J., Ghaemi, H. F., Thio, T. and Wolf, P. A., "Extraordinary optical transmission through sub-wavelength hole arrays," *Nature*, 391, 667-669, 1998.
6. Homola, J., "Surface Plasmon Resonance for Detection of Chemical and Biological Species," *chem. Rev.*, No. 108, 462-493, 2008.
7. Bigot, J.-Y., Halté, V., Merle, J.-C. and Daunois, A., "Electron dynamics in metallic nanoparticles," *Chem. Phys.*, 251, 181-203, 2000.
8. Halté, V., Benabbas, A. and Bigot, J.-Y., "Surface plasmon dynamics in arrays of subwavelength holes: the role of optical interband transitions," *Optics Express*, 16, 11611, 2008.
9. Liu, Y., Begin-Colin, S., Pichon, B. P., Leuvrey, C., Ihiawakrim, D., Rastei, M., Schmeber, G., Vomir, M. and Bigot, J.-Y., "Two dimensional dipolar coupling in monolayers of silver and gold nanoparticles on a dielectric substrate," *Nanoscale*, No. 6, 12080–12088, 2014.