Plasmonic Light Trapping in Nanostructured Metal Surfaces

Aleksandr Polyakov[1,2], Howard A. Padmore[1]
[1]*LBNL, 1 Cyclotron Road, Berkeley, CA 94720*
[2]*AS&T Graduate Group, University of California Berkeley, CA 94720*
apolyakov@lbl.gov

Stefano Cabrini, Scott Dhuey, Bruce Harteneck, Xiaogan Liang
Molecular Foundry, LBNL, 1 Cyclotron Road, Berkeley, CA 94720

Metals are commonly used as ultra-fast photoemitters for Free Electron Lasers[1] and as field concentrators for generation of harmonics in a laser-driven plasma. In these applications high optical reflectivity is problematic[1]. This is especially true of gold, silver, and aluminum, which are all efficient reflectors due to their free-electron like behavior. However, by collective excitation of electrons in the form of a plasmon, free-electron metals can completely absorb light[2]. In this work, we demonstrate a practical realization of a new method recently proposed theoretically[2] where light is converted into plasmons, which are trapped in nano-grooves (NGs). For some applications this type of coupling is advantageous due to the extremely large field enhancement and will be a powerful new tool in ultra-fast photocathode applications using multi-photon photoemission and laser harmonic generation.

The typical dimensions for the NGs are 10-15nm in width and 30-40nm in depth spaced few hundred nanometers apart. The fabrication steps are illustrated in figure 1: (a) the initial template is made by electron beam lithography from the HSQ resist on the Si substrate (b) gold is evaporated on the template, (c) the template is removed from the gold structure in the KOH bath. The cross section analysis of the resulting gold structure–see figure 1(d)–shows the slanted walls of the NG, which contributed to the reduced sample absorption efficiency (measured absorption is 80% of the theoretical model with perfect NG geometry); the reflectivity results are shown in figure 2. Comparison of the experimental data to the Finite Difference Time Domain (FDTD) modeling–based on the profile measurements–shows a good agreement.

Further improvement can be achieved by using a higher-quality template with near-perfectly smooth, vertical walls fabricated using the anisotropic KOH etch of Si (110) [3,4]. For this procedure a thin layer of thermally grown silicon oxide is used as a mask for the silicon etch. The resulting template is shown in figure 3: (a) the SEM overview of the template, with dimensions 9nm by 130nm, (b,c) a cross-section TEM view of a single nano-fin.

[1] P. Musumeci *et al*., Phys. Rev. Lett. 104(8), 084801 (2010).
[2] J. L. Perchec et al., Phys. Rev. Lett. 100(6), 066408–4 (2008).
[3] S. Y. Chou *et al*., J. Vac. Sci. Technol. B 3(6), 1567–1589 (1985).
[4] Z. Yu *et al*., J. Vac. Sci. Technol. B 21(5), 2089–2092 (2003).

(a) (b) (c) (d)

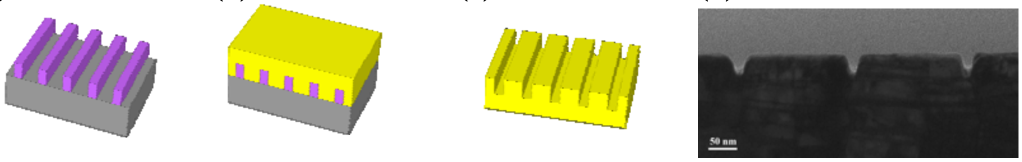


Figure 1: Sample Preparation: the HSQ resist is used as a template for fabricating the nano-structures in gold.

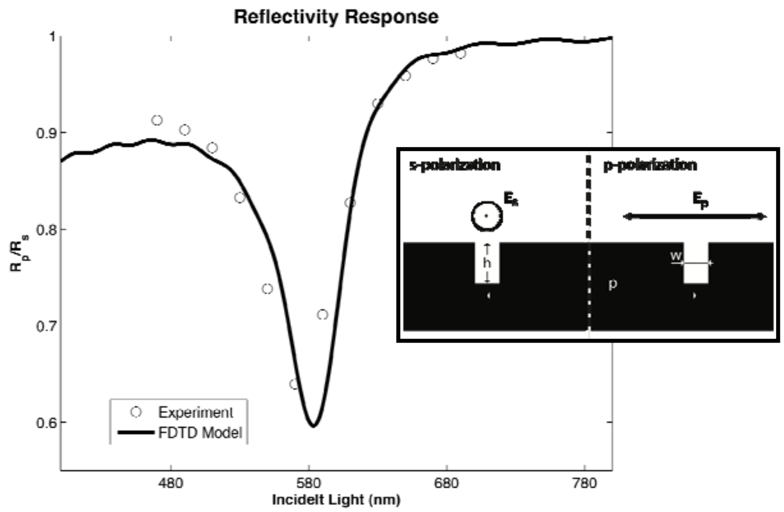
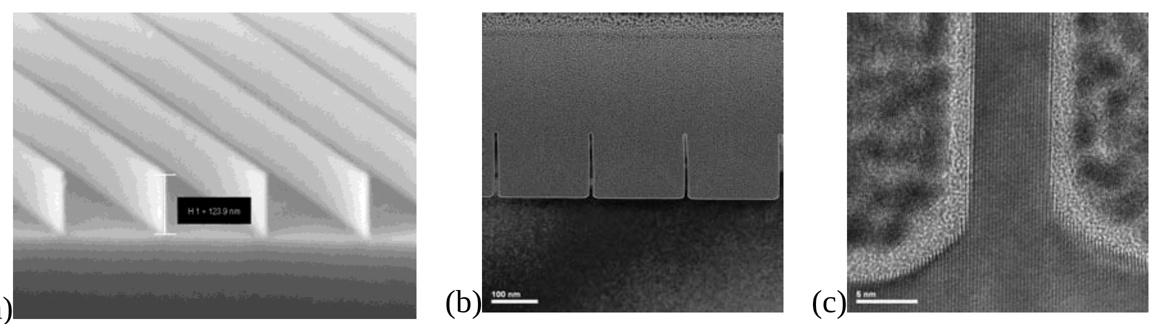


Figure 2: Reflectivity Response: The dots show data, and the solid line shows the results of a FDTD simulation, using the measured average shape of the trenches. The inset shows the definition of the s- and p-polarized light in reference to the geometry of the nano-grooves.



(a) (b) (c)

Figure 3: Anisotropic Si Etch: to improve the edge quality a template is made from silicon using the anisotropic etch of Si (110); the resulting nano-fins dimension are 9 nm (including the Si oxide layer) wide and 130 nm tall.