Fabrication and Characterization of Optical Nanogap Arrays for Plasmonic Enhancement Applications

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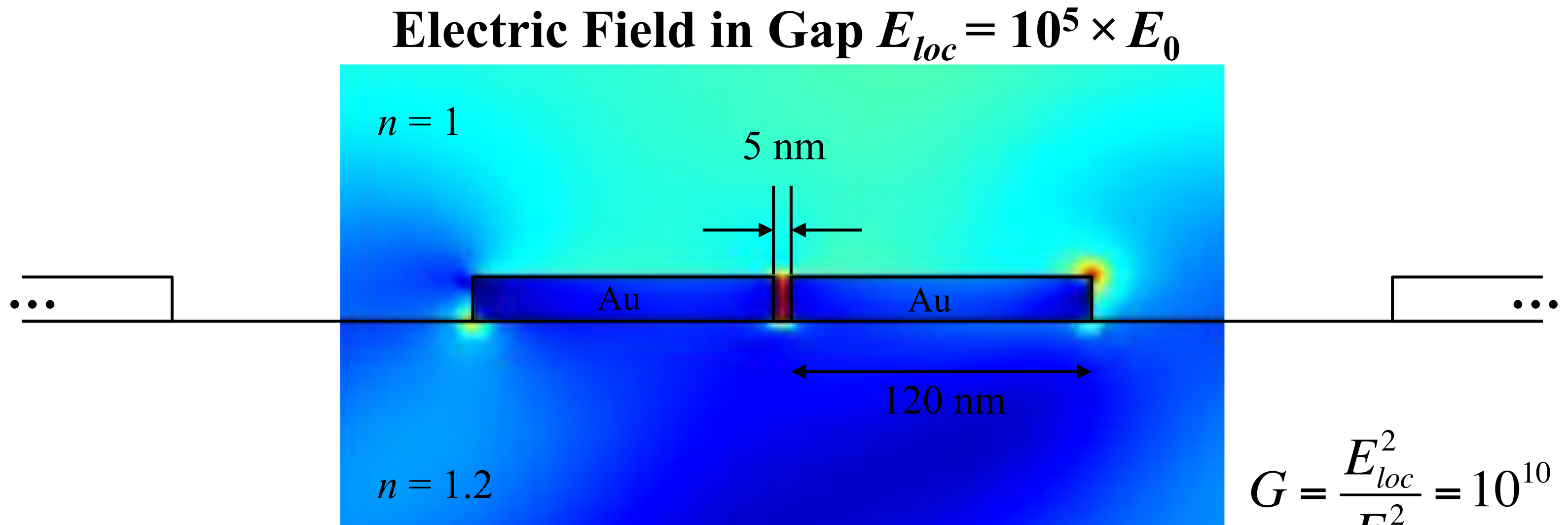
Background

The field of plasmonics has become a topic of interest for understanding optical physics at the nanoscale and its use in various applications including single molecule detection and sensing [1], plasmonically enhanced spectroscopy [2], improved photovoltaics [3], and other optoelectronic devices. Nanoscale features and geometries of plasmonic structures are key for maximizing the electromagnetic radiation enhancement of the optical devices. One of the most common nanofabrication processes is electron beam lithography (EBL), which has a minimum feature size of ~40 nm. Here we make use of a recent, previously developed, *self-aligned* process [4, 5] to overcome this limit in order to make nanoscale features on the order of 2-10 nm. Fabricating truly nanoscale gaps allows for increased and more localized plasmonically enhanced electric fields. The resulting plasmonic nanostructures behave like optical antennae that have been shown to exhibit enhanced optical properties.

Electric Field in Gap $E_{loc} = 10^5 \times E_0$



$$G = \frac{E_{loc}^2}{E_0^2} = 10^{10}$$

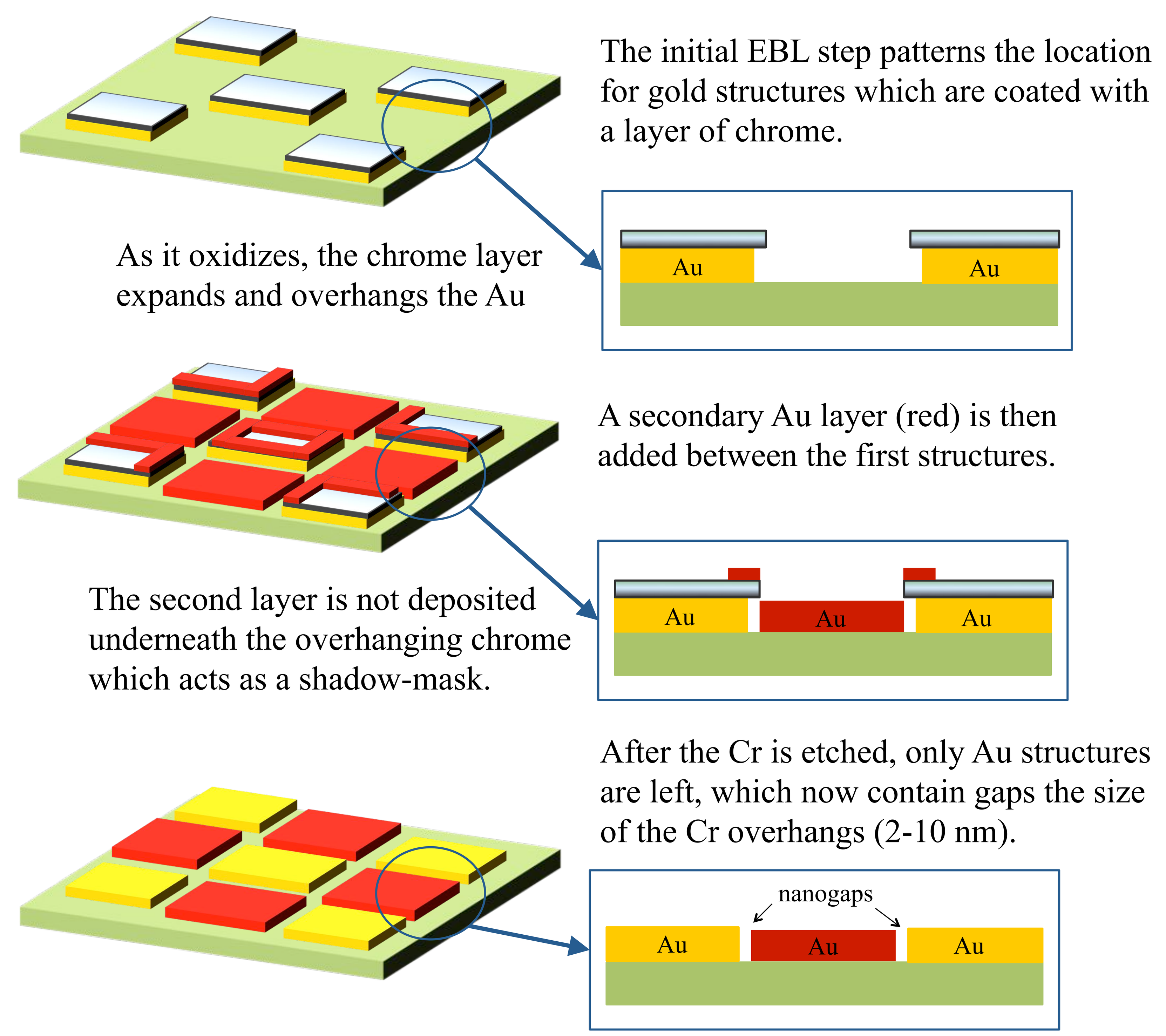
Figure 1

Computational electromagnetics

The optical response of nanogap arrays has been modeled with finite element method computational electromagnetics (COMSOL). Figure 1 shows the electric field response from a unit cell cross-section of a periodic plasmonic nanogap grating with incident light (E_0) of wavelength of 441 nm at an incident angle of 36 degrees. Enhancement (G) in the gap is by a factor of 10^{10}!

Nano Fabrication

self-aligned technique



The secondary structures could be a different metal or a different height than the initial layer. Additionally, the structures can be laid out in different patterns that would allow for similar nanogaps to be created with various geometries. The many options will produce multiple enhancement effects and allow for new capabilities in nanofabrication for any nanoscience field.

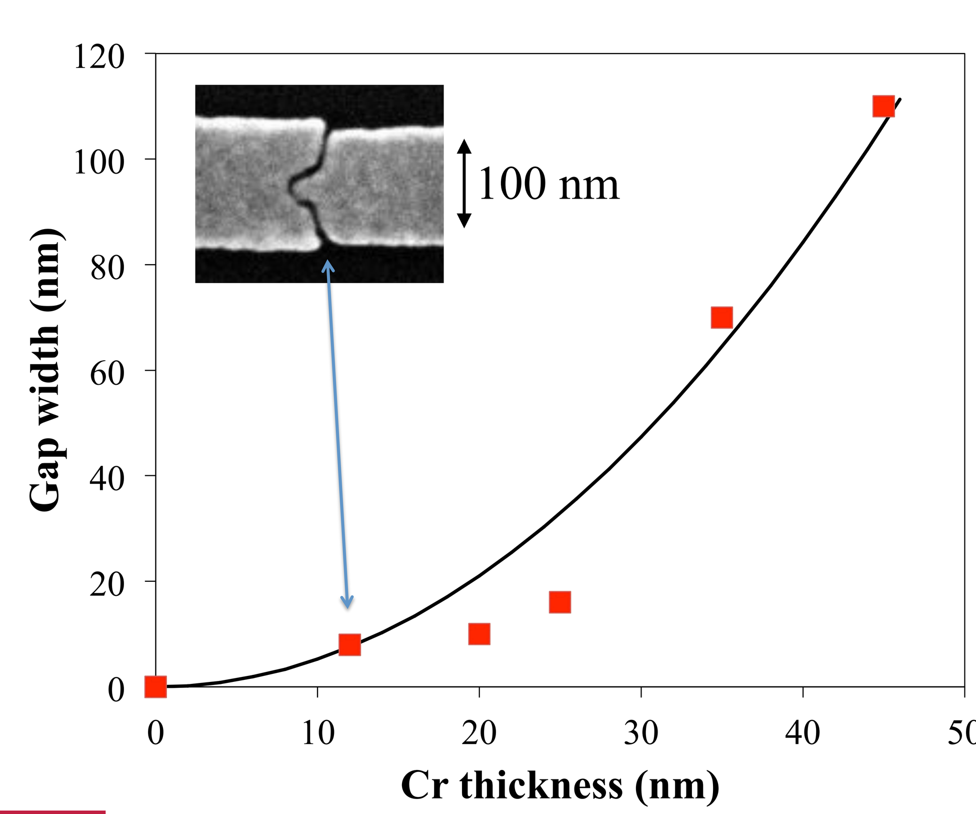


Figure 2. Dependence of the gap width as a function of Cr layer thickness. Inset: example of plasmonic nanogap device with gap ~8 nm fabricated at Rice University by J. B. Herzog (some data points extracted from [4])

Optical characterization

There are many ways to study the optical properties of plasmonic nanostructures. One of the common techniques is dark-field microspectroscopy. For this type of optical characterization, white light is used as the source which oscillates electrons, creating plasmons. The scattered light from the plasmonic nanostructures is then measured with a spectrometer which gives information about the resonant plasmonic modes that exist in the structures.

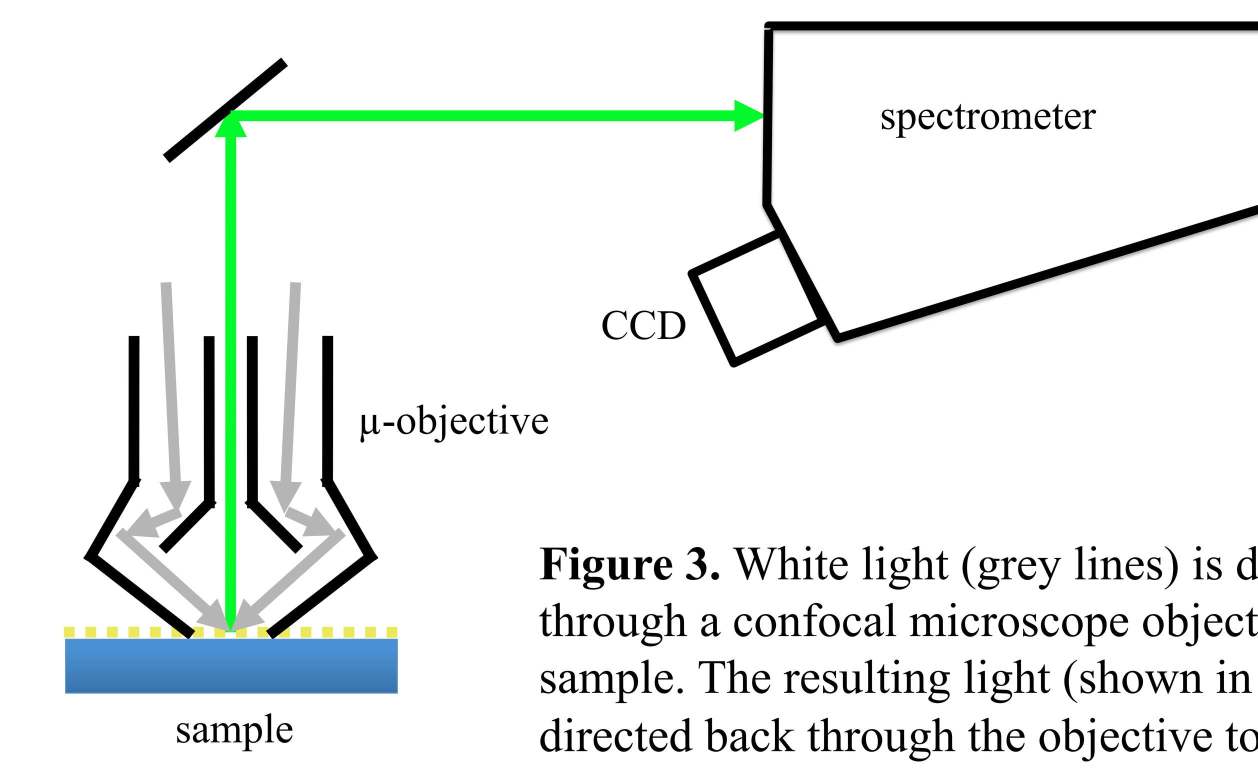


Figure 3. White light (grey lines) is directed through a confocal microscope objective to the sample. The resulting light (shown in green) is directed back through the objective to a spectrometer and attached CCD camera

Conclusion

This technique enables the fabrication of a large-area matrix of nanostructures with truly nanoscale (<10 nm) features. These structures can be used in applications of enhanced sensors, spectroscopies, and photovoltaics. In addition to their use in plasmonically enhanced applications, they will also contribute toward a better understanding of the physics of the growing field of plasmonics.

References:
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