Reaching theoretical resonance quality factor limit in coaxial plasmonic nano resonators fabricated by Helium Ion Microscope

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The concept of optical antennae has revolutionized the field of nano optics and allows in principle to manipulate and control light with a single digit nano meter resolution. This development has been made possible due to recent accomplishments in nanofabrication that has permitted structuring materials such as Au, Ag or Al with single digit nm resolution to enable plasmonic coupling between nano antennae. Hence, much of the work has been dedicated to reproducibly fabricate optical resonators with a nanometer precision using state of the art fabrication techniques such as Focused Ion Beam (FIB) milling, Electron Beam (e-beam) Lithography, and Induced Deposition Mask Lithography. However, due to the fabrication resolution limitations of > 10 nm, the optical properties of plasmonic antenna fall short of their theoretical predicated resonator quality factor and enhancement factors. Geometrical deviations from the ideal geometry – such as tapering, sidewall roughness, and corner rounding on length scales comparable to the SPP skin depth are the reasons for the shortcomings of actual optical antennae compared to their theoretical model structure.

In this work, we fabricated coaxial optical antennae that reach the theoretically predicted optical response for a perfect model coaxial structure. This is achieved by using Helium Ion Microscopy (HIM) that allows the fabrication of coaxial optical antennae with reproducible gap sizes of 8 nm, perfectly parallel sidewalls and edges with radii of curvatures of less than 4 nm. Wavelength dependent Extra Ordinary Transmission (EOT) measurements are used to determine the resonance peak and the resonance quality factor then compared to the theoretical response of an ideal geometry, determined by a numerical Finite Difference Time Domain (FDTD) simulation. For comparison, coaxial antennae fabricated using Focused Ion Beam milling were analyzed with minimum feature sizes of 30 nm, trailing substantially the theoretically predicted resonance quality factor.

In summary, we demonstrate that coaxial antennae, fabricated via HIM milling, match the theoretically predicted resonance quality factor for a flawless structure.

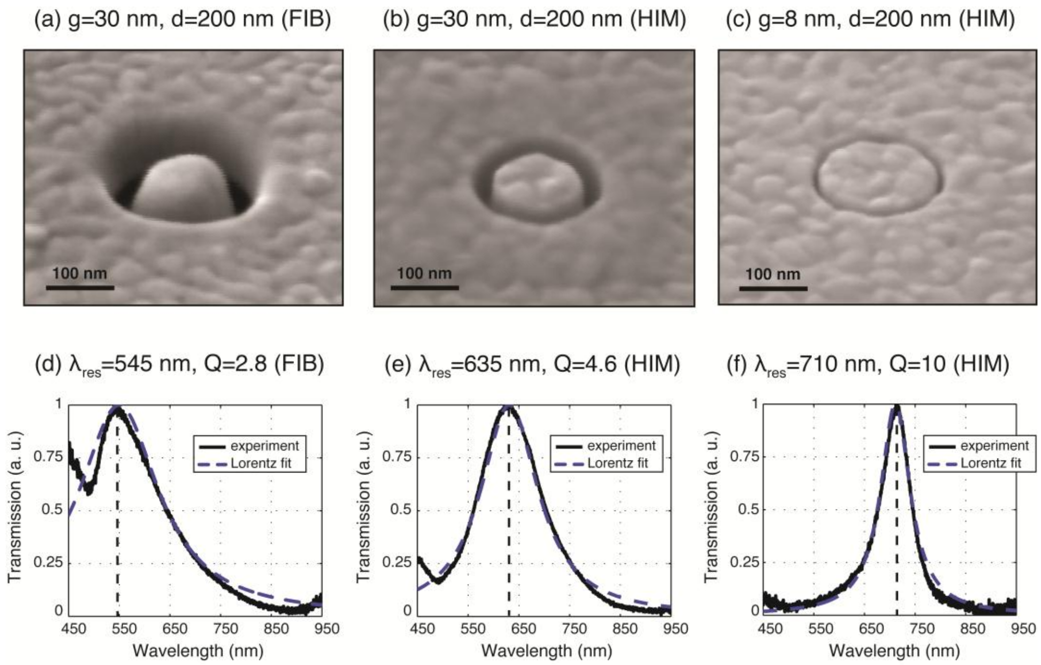

Figure 1. (a-b-c) SEM images of coaxial apertures with 200 nm diameter in a 100 nm thick gold film: a) Coax made with Ga-FIB with a nominal gap if 30 nm. b) Coax made with HIM with a nominal gap if 30 nm. c) Coax made with HIM with a nominal gap if 8 nm. (d-e-f) Corresponding transmission spectra.

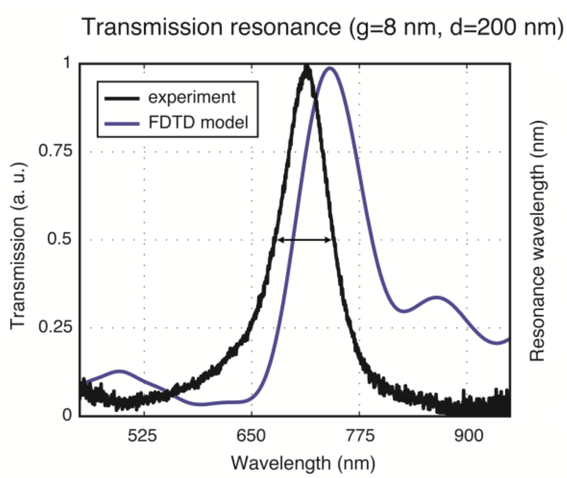

Figure 2. Transmission resonance (gap = 8 nm and diameter = 200 nm). Both, the computed resonance wavelength and Q-factor reproduce the experimental data excellently with only a minor resonance peak shift attributed to small differences in the optical constants.