Comparative study of plasmonic antennas: EBL vs. FIB fabrication

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Localized surface plasmons (LSP) are self-sustained collective oscillations of free electrons in metal nano- and microstructures (plasmonic antennas) coupled to the local electromagnetic field. Plasmonic antennas are often fabricated by electron beam lithography (EBL) process or using direct focused ion beam (FIB) patterning. The EBL process consists of following steps: (i) resist coating, (ii) electron beam patterning and resist developing, (iii) metal deposition, and (iv) lift-off and final cleaning. Contrariwise, the FIB milling consists just of two steps: (i) metal deposition and (ii) ion beam milling of the pattern. The choice of preferred fabrication technique should also consider the time and potential risks of the fabrication process. FIB preparation is simple and more straightforward as no chemistry is used. For individual antennas or small series of antennas it is rather fast. EBL preparation provides generally antennas with higher quality, but the lithographic process induces potential risks of damaging the sample as the wet chemistry is used.

In our contribution, we present a comparative study of gold plasmonic disc-shaped antennas fabricated by EBL process and direct FIB lithography. To get the highest comparability of the plasmonic antennas, both samples were fabricated and characterized simultaneously. Fabricated plasmonic antennas were characterized using the transmission electron microscopy (TEM) including the chemical analysis by energy dispersive X-ray spectroscopy (EDS) and the characterization of LSP resonances and thickness measurement by electron energy loss spectroscopy (EELS), and using atomic force microscopy (AFM) to complement information about the morphology of the structures.

EELS measurements revealed LSP resonances in both EBL and FIB-fabricated antennas. The energy of the LSP resonance is the same for both EBL and FIB antennas: 1.6 eV for 120 nm discs and 1.4 eV for 140 nm discs so it depended only on the diameter of the antennas and no difference (within experimental error) between both antenna types was observed. However, the intensity of the response (the peak magnitude of the loss probability) is higher for the EBL antennas, while the peak width is comparable. We attribute this observation partly to better structural quality and partly to low surface contamination of EBL antennas. The chemical composition of the antennas after the EELS measurement was characterized by EDS (see the Figure below) and revealed only a weak hydrocarbon contamination for EBL antennas, while for FIB antennas we observed strong hydrocarbon contamination (a layer of the thickness of 15 nm has been formed) and Ti and Ga residues of the milling process covering the area around antennas (simultaneous presence of oxygen suggests that these residues are oxidized). To conclude, we have demonstrated that the EBL antennas have better quality, but the straightforward FIB preparation is suitable fabrication alternative at the price of slightly reduced plasmonic response and stronger contamination of the antennas.

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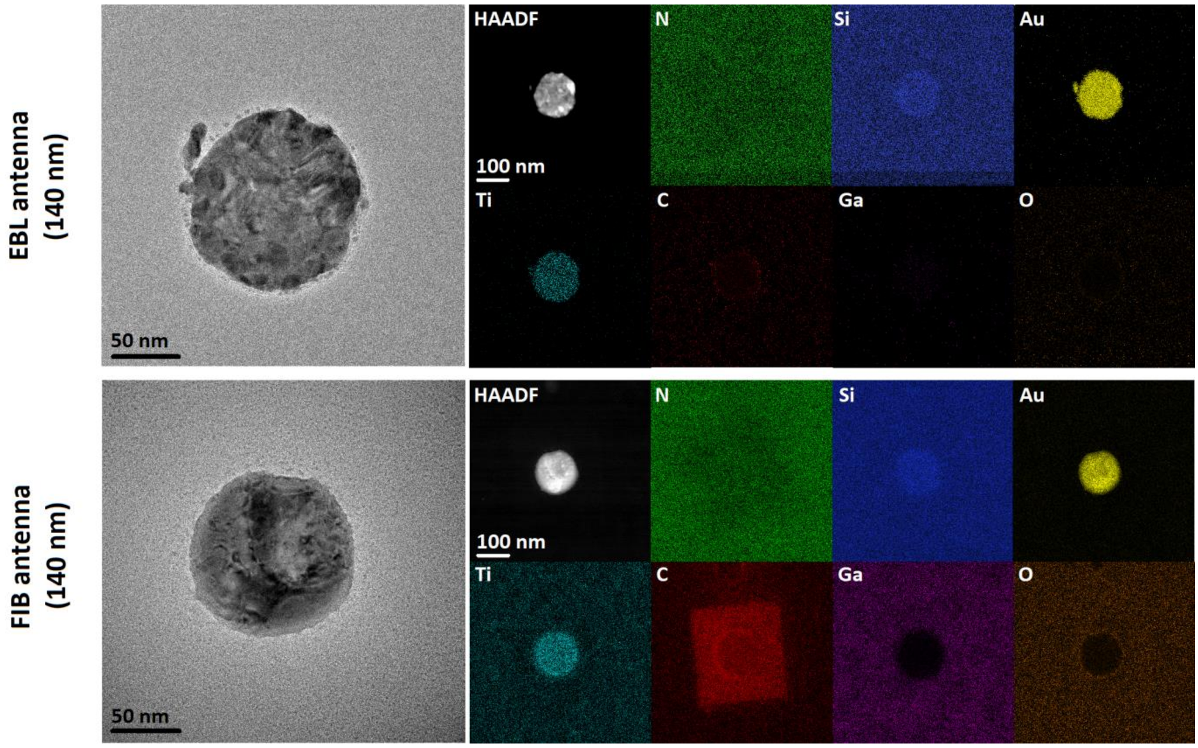

EBL antenna (140 nm)
50 nm
HAADF
N
Si
Au
100 nm
Ti
C
Ga
O
FIB antenna (140 nm)
50 nm
HAADF
N
Si
Au
100 nm
Ti
C
Ga
O