Plasmonic lightning-rod effect

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The lightning-rod effect is well known in electrostatics as the formation of a strong electric field near the sharp features of a charged conductor. Field enhancement is one of the key targets in plasmonics. Intuitively, it is expected that plasmonic structures will produce a particularly strong electromagnetic field around their features with high curvature, and this consideration translates to meticulous design of plasmonic structures with applications e.g. in enhanced photoluminescence [1] or strong light-matter coupling [2]. However, this so-called plasmonic lightning-rod effect (PLRE) is not rigorously understood despite innumerable, though ingenious studies addressing its particular aspects [3]. Importantly, the field enhancement in plasmonics stems from additional contributions besides local curvature, including the evanescent nature of surface plasmon polaritons or the magnitude of the induced charge for a specific excitation.

In our communication, we isolate the contribution of the local curvature of a plasmonic antenna (PAs) to the magnitude of the electric field of its dipole localized surface plasmon resonance. We design a set of rod-like PAs of identical length with two cylindrical terminations, one with a fixed radius r_{fix} and one with a variable radius r_{var} [Fig. 1(a)]. The PAs are investigated by electron energy loss spectroscopy (EELS) and electromagnetic simulations. At the fixed-radius end, we observe the identical loss intensity [Fig. 1(b)] and field enhancement for all the PAs. This ensures that the variations in the response at the variable-radius end can be attributed purely to the local curvature. A good quantitative agreement between the experiment and simulations verifies the validity of the simulations and allows to employ them for retrieval of the electric field, whose magnitude at the axis of the PA 20 nm away from the variable-radius end is shown as a function of the PA local radius r_{var} in Fig. 1(c). Finally, we present an intuitive phenomenological model for the induced electric field based on an effective induced point charge.

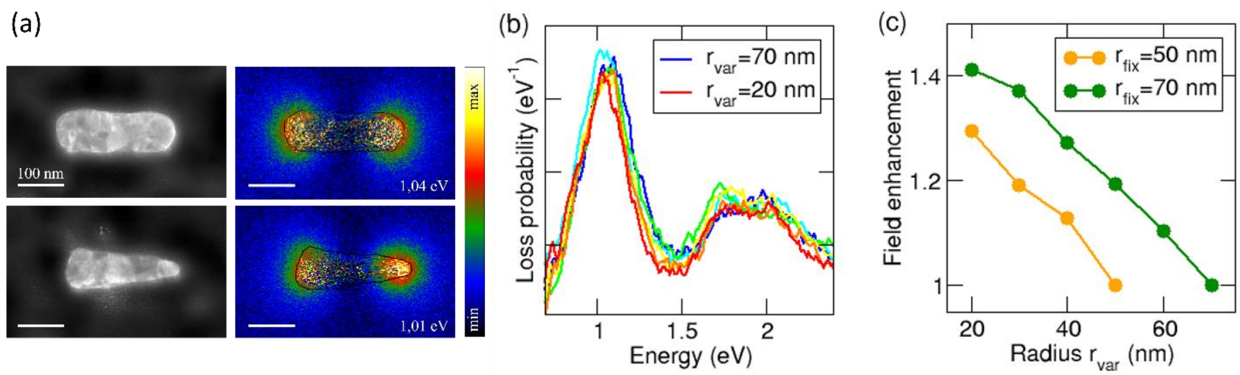

Fig. 1 (a) Two PAs with a fixed radius r_{fix} (50 nm) at the left side and a variable radius r_{var} (50 nm and 20 nm) at the right side imaged by transmission electron microscope together with EELS of their dipole localized surface plasmon resonance. The plasmonic lightning-rod effect is manifested as the intense loss signal at the sharp side of the PAs at the bottom panel ($r_{var} =$ 20 nm). (b) The loss intensity measured at the fixed-radius side of PAs demonstrates that the effects beyond the local curvature do not alter the induced field for our set of PAs. (c) The magnitude of the electric field calculated at the distance of 20 nm from a variable-radius side of the PA divided by the same quantity for $r_{fix} = r_{var}$ is displayed as a function of the local radius. Stronger fields obtained from sharper features of PAs represent the *quantified* manifestation of PLRE.

References

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