Amplifying Free-electron Evanescent Fields

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Abstract: We show experimentally for the first time that free-electron evanescent fields can be amplified by a plasmonic nanolayer in a manner analogous to the way in which optical fields are amplified in the poor-man's superlens.

The manipulation of evanescent electromagnetic fields has been a key motivation in the field of plasmonics. However, one class of evanescent field has been excluded from consideration here - the evanescent field of moving free electrons. The electromagnetic energy of free electrons exists in the form of evanescent waves and it can be out-coupled to light only when the electrons are in close proximity to a 'slow-wave medium' or optical inhomogeneity. The former causes the well-known phenomenon of Cerenkov radiation, the latter diffraction or Smith-Purcell radiation. Here, in analogy to the 'poor-man's superlens', wherein the evanescent component of light from an object is restored by a thin silver layer to beat the diffraction limit [1], we demonstrate the use of an intermediate silver layer to amplify the free-electron evanescent field before it is out-coupled into light by a nano-grating. The presence of a silver layer provides for the excitation of phase-velocity matched surface plasmons, and leads to the amplification of the electrons' evanescent field.

A grating period is chosen such that the out-coupled wavelength along the surface-normal direction matches the plasmonic resonance of the silver layer – a condition satisfied by a 130 nm period for an electron energy of 40 keV. Planarized nano-gratings are manufactured on the end faces of tapered optical fibres by focused ion-beam milling and part-coated with a 20 nm thick silver layer as shown in Fig. 1(a). The fibre face is aligned parallel to the electron beam trajectory in a scanning electron microscope (SEM) and light generated is collected via the fibre for spectroscopic analysis.

The effect of an intermediate silver film is examined by comparing peak emission wavelengths and intensities from coated and uncoated nano-gratings at electron energies between 40 and 50 keV. The silver layer enhances emission intensity by a factor of up to 2.8 at 44 keV, while also red-shifting the emission, indicating strong coupling of the electron evanescent field to surface plasmons on the silver (see Fig. 1 (b)).

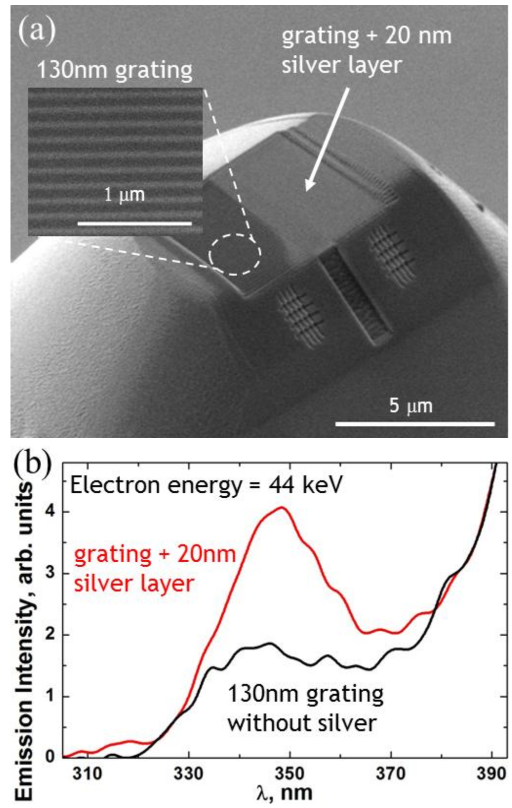

Fig. 1: (a) Electron microscope image of a tapered multi-mode optical fiber end face on which a planarized, 130 nm period aluminum grating has been manufactured and partially coated with a 20 nm layer of silver. (b) Electron-beam-driven light emission spectra from gratings with (red) and without (black) the silver film.

The idea of introducing an intermediate layer of plasmonic metal to enhance free-electron evanescent fields can readily be applied to any part of the electromagnetic spectrum by suitably engineering the nanostructure. Furthermore, the configuration pioneered in this experiment could serve as a platform for investigating proximity interactions between free electrons and a wide range of nanophotonic structures.

References:

[1] J. B. Pendry, *Phys. Rev. Lett.* **85**, 3966 (2000)