Proximity Interactions of Free-electrons with Metamaterials and Plasmonic Nanostructures

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Abstract

We introduce an optical fiber platform to interrogate the proximity interaction between free electron evanescent fields and photonic nanostructures at optical frequencies. Conically profiled optical fiber tips are functionalized with nano-gratings, thin silver film on nano-gratings, and metamaterials for the detection, amplification, and controlled coupling of electron evanescent fields.

With the advancements in electron microscopy, the spectroscopic techniques based on electron beam are widely used to get the photonic information of nanophotonic structures such as photonic crystals, metamaterials, and plasmonic nanostructures. In so doing, free electrons provide unique opportunities in pumping or probing such nanostructures with their unrivalled broadband and localized excitation capability compared to ordinary light illumination. Although such pumping and probing are mainly based on the direct electron bombardment of the sample structures, it can also be achieved by remote interaction via moving electrons' evanescent fields. However, the interrogation of such remote interaction between free electrons and nanophotonic structures at the optical frequencies has been hampered by the absence of a suitable experimental platform. Here, we discuss an optical fiber platform which was recently introduced to study such proximity interaction at the nano-scale.

The optical fiber platform (see Fig. 1a) plays two major roles: 1) tapered substrate for nanophotonic structures; 2) light-pipe for the collection of the out-coupled electron evanescent fields. In this manner, the luminescence arising from electrons hitting the substrate material can be minimized and the need for independent light-collection optics which is highly positionally sensitive to the alignment of optical and electron beam foci in three dimensions and intrusive to electron optics can be eliminated. Thus, the proximity interaction between free electron evanescent fields and various nanophotonic structures can be studied by simply putting such structures on the fiber platform.

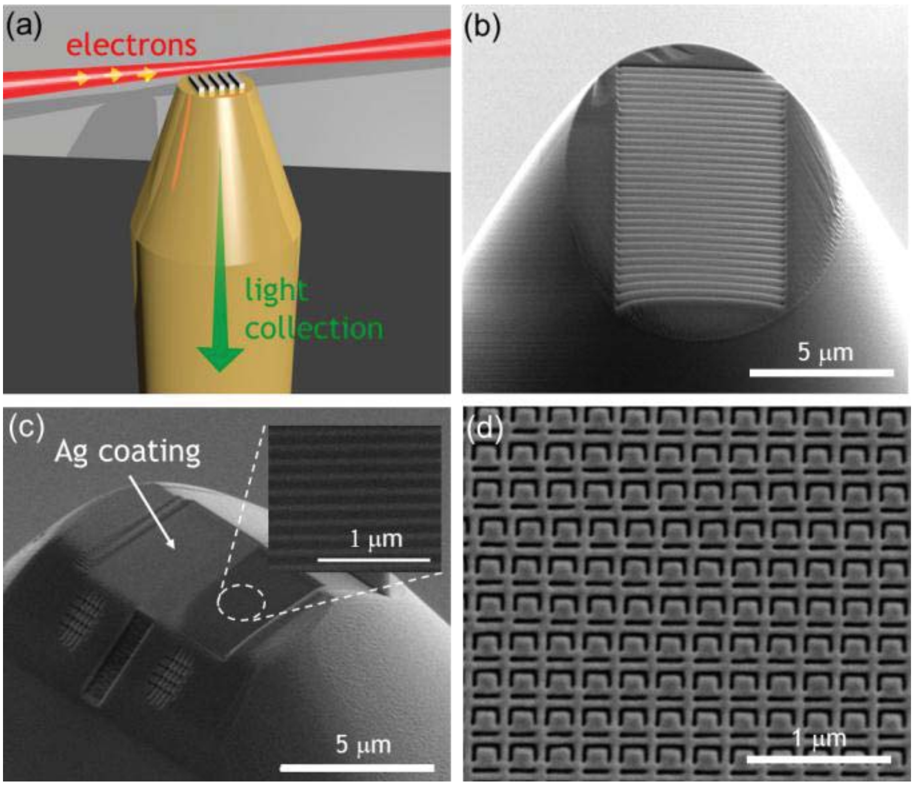

Figure 1: (a) Artistic impression of an optical fiber platform with the presence of a nano-grating and moving electrons. Electron microscope images for (b) a 256 nm period grating, (c) a 130 nm period grating partly coated with 20 nm silver film, and (d) asymmetric split ring metamaterials fabricated by focused ion beam milling on the end facet of optical fiber tips.

Figure 1 shows exemplary nanophotonic strucutures studied so far. In all cases, a medium-energy electron beam (30-50 keV) in a scanning electron microscope was used. A nano-grating in Fig. 1b enables the detection of the evanescent field components of moving free electrons via diffractive coupling, so-called Smith-Purcell effect. By putting a thin silver layer (~30 nm), the aforementioned evanescent field can be amplified in the same manner as the optical evanescent field is amplified in the 'poor-man's superlens' (Fig. 1c). Plasmonic metamaterials can resonantly enhance the involved energy coupling and tailor the strengths of various diffraction orders (Fig. 1d). Further details will be discussed.

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