Control of Free-electron Light Emission via Metasurfaces and Plasmonic Nanostructures

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***Abstract*—We will review our recent experimental demonstrations on controlling the light emission from moving free-electrons either by proximity interaction or impact at optical frequencies. Carefully designed metasurfaces and plasmonic nanostructures enable the amplification and wavefront manipulation of such light emission.**

I. INTRODUCTION AND BACKGROUND

FREE-ELECTRONS moving in vacuum can generate light emission in various ways and they are used as an intense source of coherent light covering a wide range of the electromagnetic spectrum from RF to X-ray. Among such light generation mechanisms, those based on linearly moving free-electrons offer a versatile platform for compact tunable light sources and serve as a probe of nanostructures with ultimate spatial resolution in modern electron microscopes. Here, we experimentally demonstrate that light emission from such electrons can be controlled and significantly enhanced with the help of plasmonic nanostructures and metasurfaces either via proximity or impact interaction at optical frequencies.

II. RESULTS

Free-electron light emission via proximity interaction relies on the fact that free electrons moving in vacuum carry evanescent electromagnetic fields. These evanescent fields can be out-coupled by placing a ‘slow-wave medium’ or an optical inhomogeneity near the moving electrons. Recently, we introduced tapered optical fiber probe tips (Fig. 1a) [1], akin to those employed for sampling evanescent light fields in near-field microscopy, such that their interaction with free electrons can be diagnosed with fiber-coupled UV/visible light.

With this fiber platform, we demonstrated that the evanescent fields of medium energy electrons (20-50 keV) can be sampled by diffractive coupling [1] and amplified by the resonant excitation of phase-velocity matched surface plasmons. While the amplification by plasmonic thin films relies primarily on material properties, we show that plasmonic metasurfaces can offer tunability by design.

On the other hand, free-electron impacts generate transition radiation with a dipolar emission distribution and surface plasmons propagating with cylindrical symmetry away from the excitation point. This electron-induced light emission has been serving as an essential tool to study the energy coupling of single dipole emitters such as quantum dots or fluorescent molecules to the photonic modes supported by nanophotonic structures. Here, we demonstrate that the wavefront of light emanating from such singular nanoscale emitters can be manipulated by holographically designed nanostructures. Locating such a source within an engineered nanostructural environment enables the conversion of typically highly divergent and often spectrally broad radiation patterns into virtually any desired wavefront with controlled directionality, divergence and spectral composition (Fig. 1b).

The concepts of controlling free-electron light emission demonstrated here can be readily applied to THz frequency regime by appropriate scaling of the designs.

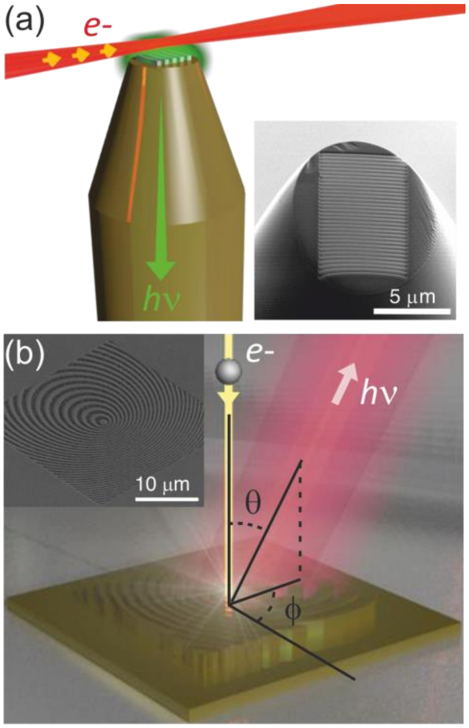

Figure 1. (a) Artistic impression of an optical fiber probe for electron evanescent fields. (inset) SEM image of a 256 nm period grating on the end facet of a Cr-coated truncated conical fiber probe tip. (b) Artistic impression of wavelength, direction and divergence controlled far-field light emission from an electron impact point-source on a holographically nanostructured surface. (inset) SEM image of a holographic structure to generate a low-divergence 800 nm output beam at $\theta = 30°$ to the surface normal.

REFERENCES

[1] J. K. So, K. F. MacDonald, N. I. Zheludev, “Fiber optic probe of free electron evanescent fields in the optical frequency range,” *Appl. Phys. Lett.* 104, 201101 (2014).