Apparatus for studying low energy electron-photon interactions inside a Scanning Electron Microscope

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On-chip, nanostructure-mediated electron-photon interactions provide a path toward wavelength-tunable electron-controlled light sources[1]. Possible applications range from quantum metrology to compact, highly-tunable light sources for photonics in the broader sense. Lately, there has been significant progress in the study of the generation of coherent, near-visible light sources that rely on the interaction of high (> 100 keV) energy electrons with nanostructured surfaces[2]. These high electron energies are however unfeasible for the development of chip-scale based devices.

In this work, we present an apparatus for studying nanostructure-mediated electron-photon interactions at low (< 10 keV) electron energies (figure 1a). Central to our approach is the patterning of nano-sized structures directly onto the tip of a fiber optical core[3] that acts as an electron-photon interaction region. The propagation of the free-space electron beam in the vicinity of these structures is then expected to yield emission of photons into the fiber (figure 1b). During this process, the free-space electron transfers a fraction of its energy towards the emitted photon, resulting in a kinetic energy-loss depending on the emitted photon wavelength.

An inhouse built electron spectrometer is positioned below the interaction region to enable the observation of this energy loss. For improved beam positional awareness, we are employing a novel method in which an active PN edge junction is placed on the opposite side of the optical axis in front of the interaction region. A line scan of the electron beam across the edge towards the interaction region then leads to a measurable voltage signal as the beam leaves the detector surface area. This provides us with a reference point for the electron beam position at that point in time.

Basic applications for the setup include the study of single-particle Smith-Purcell radiation, and electron-heralded photon emission and vice versa. Future expansions of the experimental setup would consist of adding alternative interaction mechanisms, such as photo-induced conditioning of the wavefront of the electron wavefront prior to, or after, interaction of the electron with the patterned fiber, or multiple photon generation regions, which would allow for the generation of quantum mechanical superposition states of photons.

References

[1] Nature Communications, vol. 10, no. 1, pp. 1–8, Jul. 2019, DOI: 10.1038/s41467-019-11070-7
[2] Cavity-mediated electron-photon pairs, Science, Vol 377, pp. 777-780
[3] Appl. Phys. Lett 104, 201101, 201

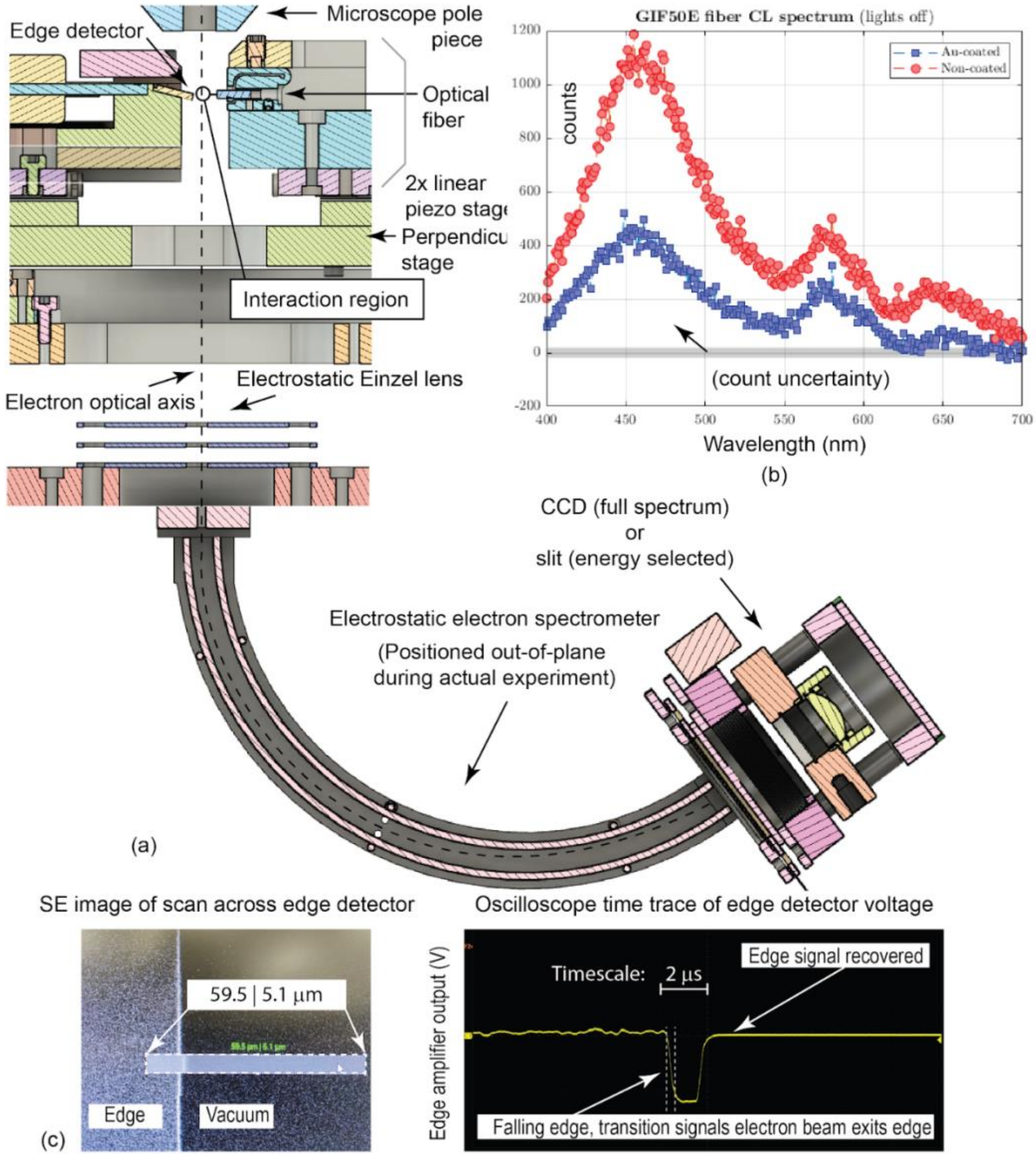

Figure 1. (a) Schematic of our apparatus design, showing the main optical components and detectors. (b) Example of cathodoluminescence data obtained by scanning the electron beam across the tip of a Thorlabs GIF50E lens-tipped optical fiber. Red circle markers label for an uncoated fiber, and the blue rectangular markers label for a ~ 40 nm Au-coated layer on top (preliminary data). (c) Line scan of the electron beam across the edge detector and the obtained time trace of the output amplifier.