Free-electron pumped tunable nanoscale light-source: the "light-well"

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Purpose
We report on the first experimental demonstration of a new type of electron-beam-driven radiation source, a 'light-well', which can be used as a tunable nanoscale emitter of optical radiation and surface plasmon-polaritons (SPPs).

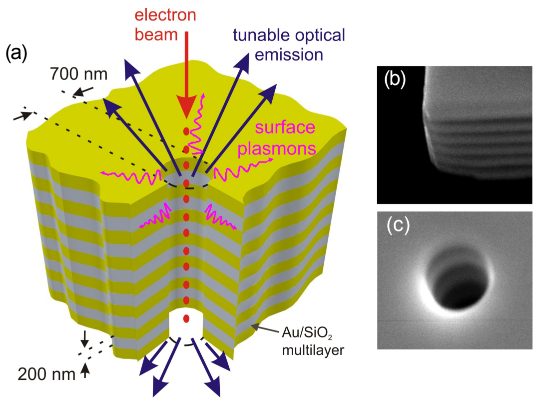

Figure 1: (a) Schematic section of a light-well. (b) Secondary electron images of the gold-silica multilayer and of a light-well (c).

Methods
In a free-electron laser (FEL) a beam of electrons emits light as it passes through an 'undulator' – a region of alternating magnetic fields. Similarly, in the light-well a beam of free-electron generates optical photons and SPPs via exposure to a periodic dielectric environment as it passes through a cylindrical nano-hole in a layered metal-dielectric structure. The emission wavelength can be tuned by changing the electron energy. The source has an optical output power of the order of 0.1 nW which corresponds to an emission intensity of ~200 W/cm^2.

Experimental light-well nano-holes were milled, using a focused ion beam, through a multilayer stack of alternating 200 nm gold and silica layers sputtered onto a silicon substrate (Fig. 1). Experimental measurements of light-well optical emission were performed using the hyperspectral imaging mode [1] of a scanning electron microscope equipped with a spectrograph and nitrogen-cooled CCD array for detection and analysis of emitted light.

Results
When an electron beam is injected into a light-well nano-hole, the emission spectrum is found to contain two peaks (Fig. 2a) with spectral positions that depend on the electron acceleration voltage (Fig. 2b). The total emission intensity is found to increase with beam current and as the injection point approaches the wall of the light-well, and to decrease with the well diameter.

Light-well output results from a combination of material- and geometry-dependent electron-beam-induced emission processes, including Smith-Purcell radiation [2] and SPP excitation on the numerous metal-dielectric interfaces within the structure. In analyzing light-well emission characteristics, we consider the electromagnetic modes supported by periodically structured nano-cavities (Fig 2b) and numerically model light-well structures using the boundary element method [3].

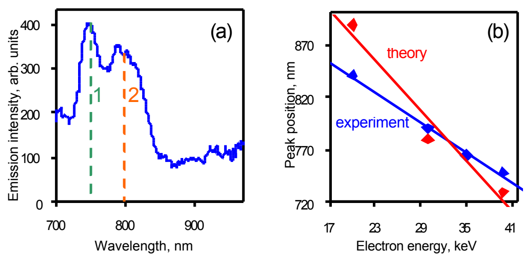

Figure 2: (a) Emission spectrum of a 700 nm diameter light-well for 40 keV electrons injected at a point ~100 nm inside the wall of the well. (b) Spectral position of peak 1 in experiments (blue) and theory (red).

Conclusions
With dimensions of a few hundred nanometers and a structure compatible with silicon-based technologies, the light-well may be employed in highly-integrated nanophotonic circuits as chip-scale free-electron radiation sources, or in densely packed ensembles for optical memory or 'surface-conduction electron-emitter' and field-emission display applications.

References
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