Using single quantum dots to probe nanowires

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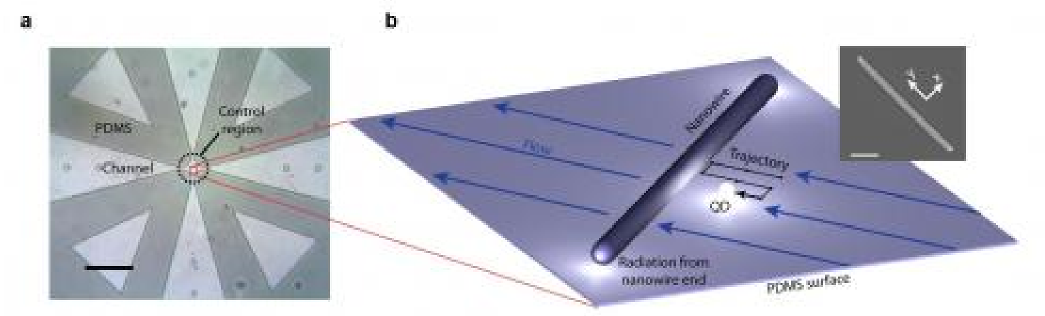

(a) This is an optical image of the microfluidic crossed-channel device. Flow in the center control region (dashed circle) is manipulated in two dimensions by 4 external electrodes (not shown). Scale bar is 500 µm. (b) This is a schematic of the positioning and imaging technique. A single QD is driven along a trajectory close to the wire by flow control. The inset shows a microcope image of a typical nanowire with 1 µm scale bar. Credit: JQI

Modern telecommunications happens because of fast electrons and fast photons. Can it get better? Can Moore's law—the doubling of computing power ever 18 months or so—be sustained? Can the compactness (nm-scale components) of electronics be combined with the speed of photonics?

Well, one such hybrid approach is being explored at the Joint Quantum Institute, where scientists bring together three marvelous physics research fields: microfluidics, quantum dots, and plasmonics to probe and study optical nanostructures with spatial accuracy as fine as 12 nm.

PLASMONICS

When light strikes a strip of metal an electron wave can be excited in the surface. Is this "surface plasmon" a bit of light or electricity. Well, it's a bit of both. The wavelength of this electromagnetic wave is shorter and the energy density higher than that of the incoming laser light; the plasmon is thus tightly localized light constrained to propagate along the meal surface. The science of "plasmonics" has arisen to capitalize on various imaging, sensing, and processing abilities inherent in plasmons. To start with, though, one needs to know exactly what happens at that laser-excited metallic surface. That light is converted into the plasmonic wave; later the energy can be reconverted into light.

Here's where the JQI experiment comes in. The main result of the work, published February 5 in the journal *Nature Communications*, is to provide a map showing how the metal strip, in this case a silver wire 4 microns long and 100 nm wide, lights up.

MICROFLUIDICS AND QUANTUM DOTS

The other two chief components of the experiment, in addition to plasmonics, are microfluidics and quantum dots. Microfluidics, a relatively new science all by itself, features the movement of nanoliter volumes of fluids through channels defined on microchips, analogous to the conducting paths strung across microprocessors for carrying electrical currents. Quantum dots, nanometer-sized semiconductor balls, are tailored to possess a specified set of allowed energy states; in effect the dots are artificial atoms that can be moved around. In the JQI experiment the 10-nm-wide dots (the important cadmium-selenide layer is only 3 nm thick) float in a fluid whose flow can be controlled by varying an applied voltage. The dots are drawn up close to the nanowire as if they were mines next to a submarine.

Indeed the dot is there precisely to excite the wire. The dot is fluorescence machine—-in a loose sense a nanoscopic lightbulb. Striking it with green laser light, it quickly re-emits red light (one photon at a time), and it is this radiation which excites waves in the nearby wire, which acts like an antenna. But the interaction is a two-way street; the dot's emissions will vary depending on where along the length of the wire it is; the end of the wire (like any pointy lightning rod on a barn) is where electrical fields are highest and this attracts the most emission from the dot.

A CCD camera captures light coming from the dots and from the wire. The camera qualities, the optical properties of the dot, the careful positioning of the dot, and the shape and purity of the nanowire combine to provide an image of the electric field intensity of the nanowire with 12-nm accuracy. The intensity map shows that the input red light from the quantum dot (wavelength of 620 nm) has effectively been transformed into a plasmonic wavelength of 320 nm.

Chad Ropp is a graduate student working on the project and the lead author on the paper. "Plasmonic maps have been resolved before, but the quantum mechanical interactions with a single emitter have not, and not with this degree of accuracy," said Ropp.

POSSIBLE APPLICATIONS

In an actual device, the quantum dot could be replaced by a bio-particle which could be identified through the nanowire's observed effect on particle's emissions. Or the dot-wire duo could be combined in various configurations as plasmonic equivalents of electronic circuit components. Other uses for this kind of nanowire setup might exploit the high energy density in the plasmonic state to support nonlinear effects. This could enable the nanowire-dot combination to operate as an optical transistor.

More information: "Nanoscale imaging and spontaneous emission control with a single nano-positioned quantum dot," Chad Ropp, Zachary Cummins, Sanghee Nah, John T. Fourkas, Benjamin Shapiro, Edo Waks, *Nature Communications*, paper published online 5 February 2013.

Provided by Joint Quantum Institute