A qubit candidate shines brighter

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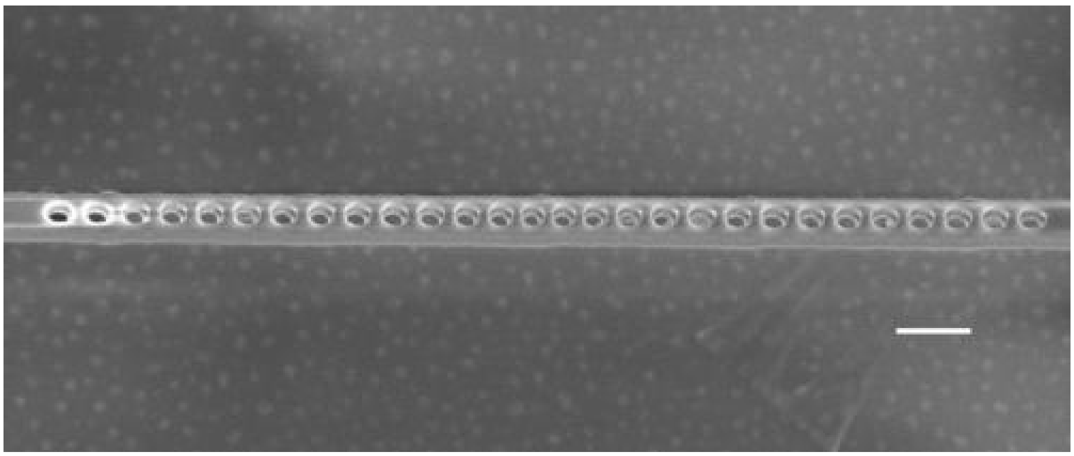

A scanning electron microscope image of the diamond photonic cavity shows the nanoscale holes etched through the layer containing NV centers. The scale bar indicates 200 nanometers. Credit: Evelyn Hu/Harvard

In the race to design the world's first universal quantum computer, a special kind of diamond defect called a nitrogen vacancy (NV) center is playing a big role. NV centers consist of a nitrogen atom and a vacant site that together replace two adjacent carbon atoms in diamond crystal. The defects can record or store quantum information and transmit it in the form of light, but the weak signal is hard to identify, extract and transmit unless it is intensified.

Now a team of researchers at Harvard, the University of California, Santa Barbara and the University of Chicago has taken a major step forward in effectively enhancing the fluorescent light emission of diamond nitrogen vacancy centers - a key step to using the atom-sized defects in future quantum computers. The technique, described in the journal *Applied Physics Letters*, from AIP Publishing, hinges on the very precise positioning of NV centers within a structure called a photonic cavity that can boost the light signal from the defect.

A Potential Qubit Power Couple

NV centers contain an unpaired electron that can store information in a property known as spin. Researchers can "read" the spin state of the electron by observing the intensity of particular frequencies of the light that the NV center emits when illuminated by a laser.

At room temperatures, this pattern of light emission couples to multiple "sideband" frequencies, making it difficult to interpret. To amplify the most important element of the signal researchers can use a structure called a photonic cavity, which consists of a pattern of nanoscale holes that serve to enhance the NV center's light emission at its main frequency.

"A photonic cavity that is properly matched to the NVs can substantially augment their capabilities," said Evelyn Hu, a researcher at Harvard whose group studies the optical and electronic behavior of materials that have been carefully sculpted at the nanoscale.

NV centers whose signal is enhanced by photonic cavities could act as qubits, the fundamental units of quantum information in a quantum computer.

Matchmaker, Matchmaker, Make Me a Match

Photonic cavities best enhance the signal of NV centers located in a "hot spot" where the cavities' resonant fields are strongest, but making sure an atom-sized defect's location matches up with this spot is extremely tricky.

"Strong spatial overlap is the hardest [task] to achieve in designing and fabricating a photonic cavity for NV centers," Hu said.

She compared the task to turning on a fixed small light beam in a dark room containing ultra-small transmitters that send out information once they are illuminated by the 'right' beam. If the match is right, the signal from the transmitter is returned strongly, but the challenge is that the chances of the light hitting the transmitter are very small.

Hu and her colleagues ultimately aim to make sure the beam (or field of the photonic cavity) will always hit the transmitter (or NV center), so that information will always be read out. They can do this by knowing the exact position of the tiny NV centers.

The team took an important first step toward this goal by controlling the depth of the diamond defects using a technique called delta doping. "Integrating a plane of spins into these structures enables us to engineering the spin-photon interaction and exploit quantum effects for future technologies," said David Awschalom, a researcher at the University of Chicago whose group grows and characterizes these systems. The technique confines the possible location of NV centers to a layer approximately 6 nanometers thick sandwiched inside a diamond membrane approximately 200 nanometers thick. The researchers then etched holes into the membrane to create the photonic cavities.

Using this method the researchers were able to increase the intensity of the light emitted by the NV centers by a factor of about 30 times.

The team believes they can further enhance the emission by also controlling the position of the defects in the horizontal plane and are currently working on possible ways to achieve full 3-D control.

Computers, Sensors and More

Nitrogen vacancy centers aren't the only candidate for qubits, but they have attracted a lot of interest because their electrons have long spin lifetimes at room temperature, meaning they can maintain quantum information for a relatively long time.

And the promise of NV centers doesn't stop at ultrafast computers. NV centers can also be used in non-computing applications, for examples as molecular-scale magnetic and temperature sensors that could measure the properties within single cells.

More information: "Deterministic coupling of delta-doped NV centers to a nanobeam photonic crystal cavity, *Applied Physics Letters* , December 29, 2014. DOI: 10.1063/1.4904909

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