# Engineering the Charge Occupancy of Nitrogen Vacancies in Diamond

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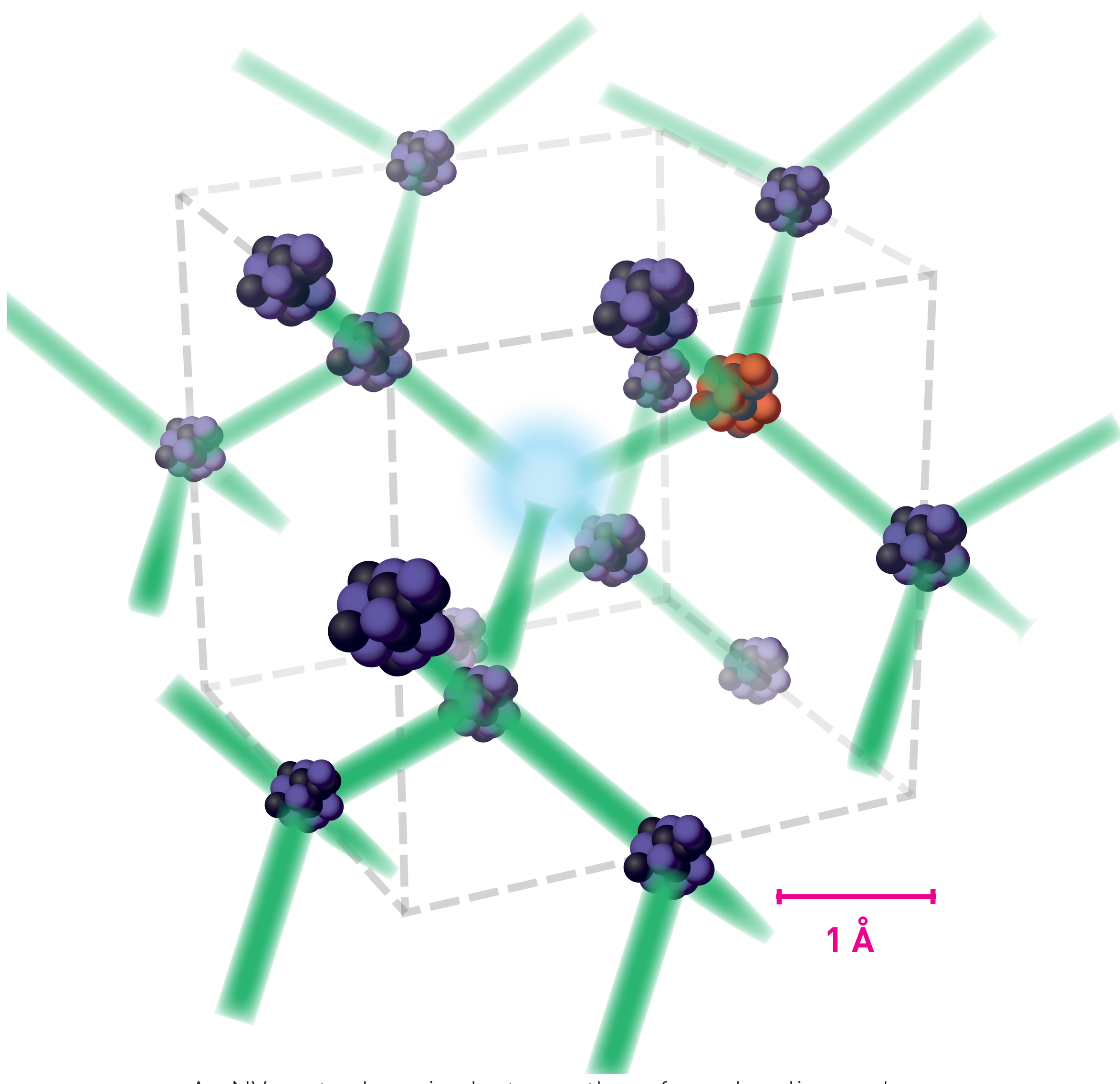
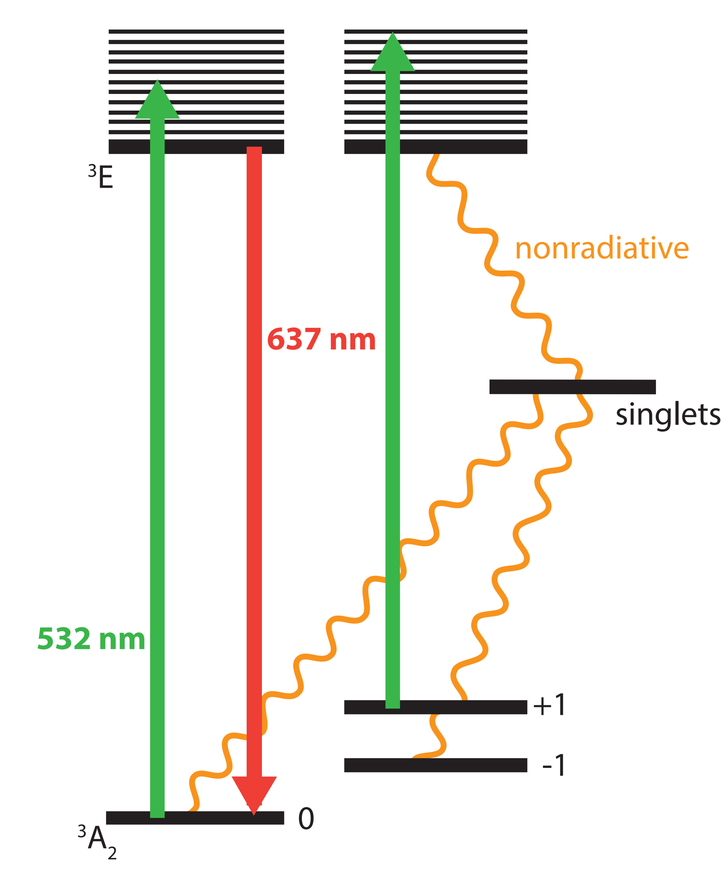
## Concept

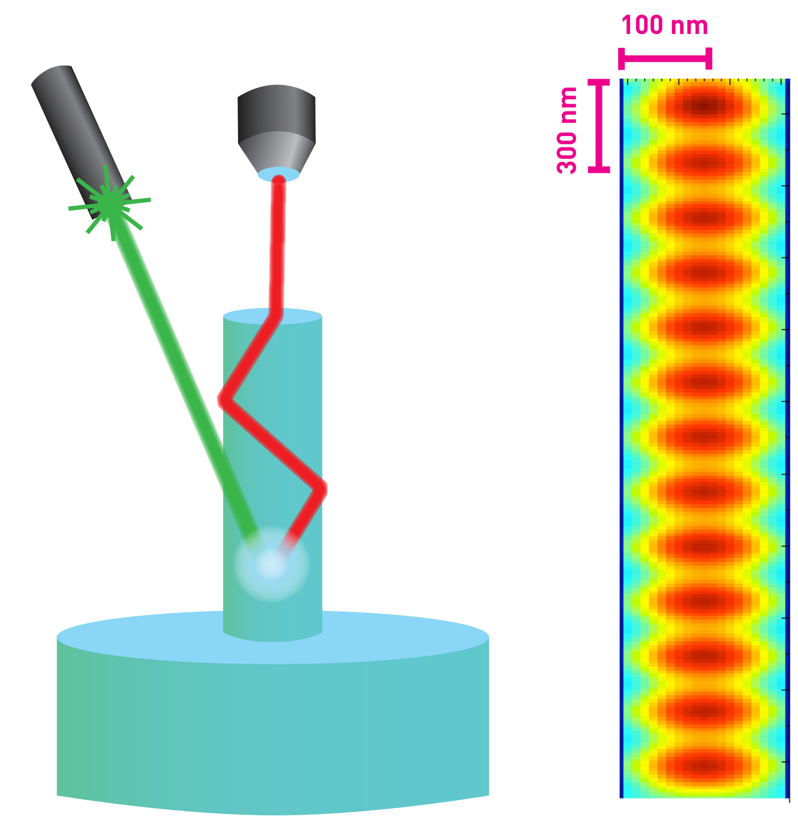
The project seeks to control the fluorescence of nitrogen vacancy (NV) centers, point defects in a diamond lattice with optical properties that depend on their magnetic environment. This makes them promising platforms for optical magnetic field measurement and spin-based quantum computing.



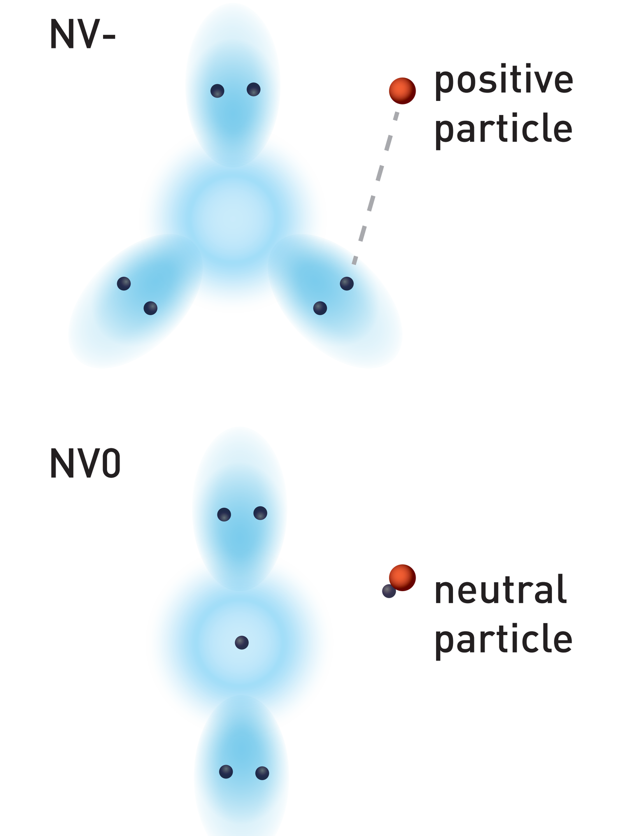

An NV center has six electrons, three from dangling carbon $sp^3$ orbitals, two from the nitrogen lone pair, and one captured from the conduction band due to nitrogen's electronegativity.




The energy levels of the NV center are determined by the various symmetric arrangements of the electrons in the defect. The defect fluoresces more brightly when the electron arrangement has a total spin of zero



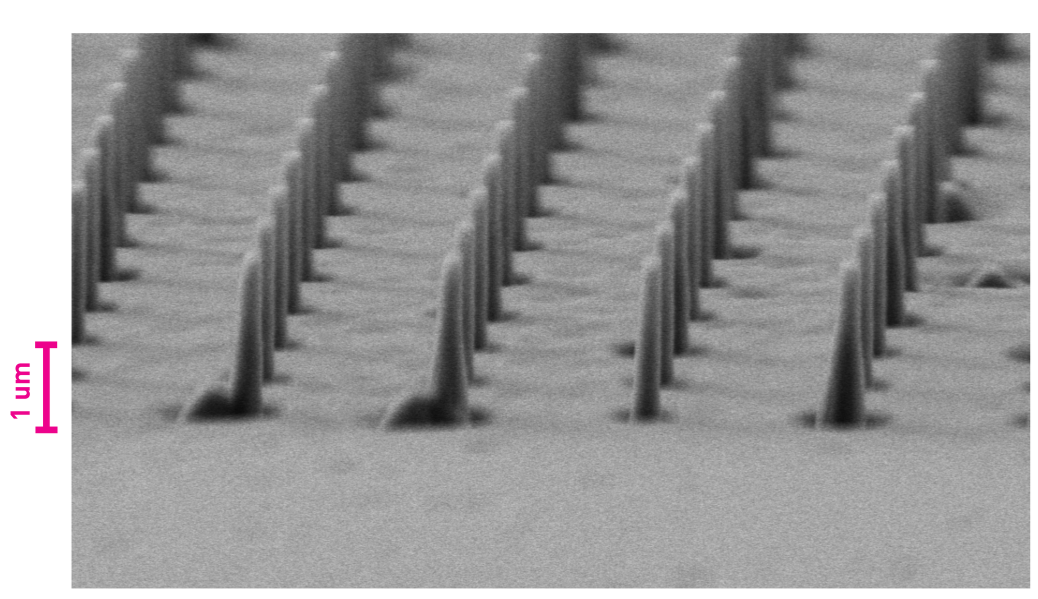

Diamond nanowires may be used to channel light from a laser onto nitrogen vacancies, allowing the center to be more easily excited and allowing resultant fluorescence to be more easily measured. The finite element simulation (right) shows the wire acting as a waveguide.



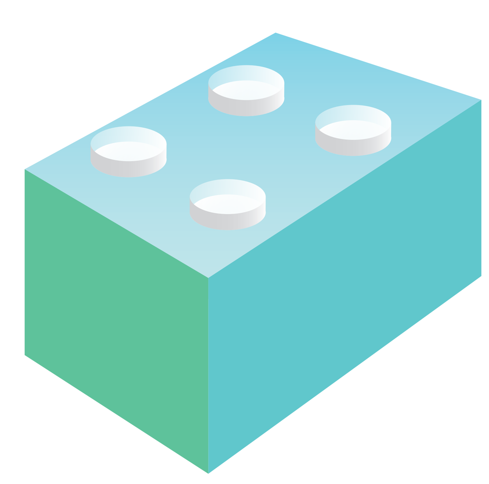

Stray positive charges, such as holes or diffusing ions, can capture electrons from the NV center, altering its energy level structure and changing its fluorescent properties. The project seeks to prevent this process.

## Approach

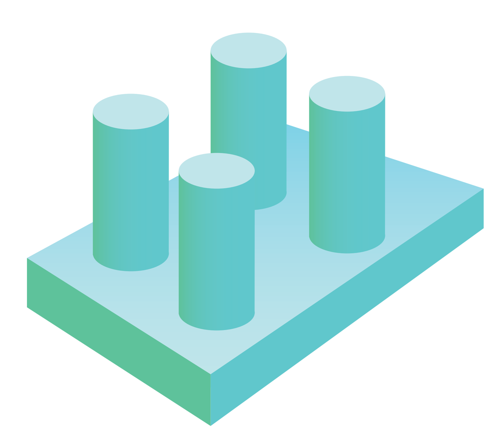
Nanowires are created in bulk diamond using a top-down fabrication process. The wires are then directionally implanted with various ions in order to introduce additional defects or carriers.



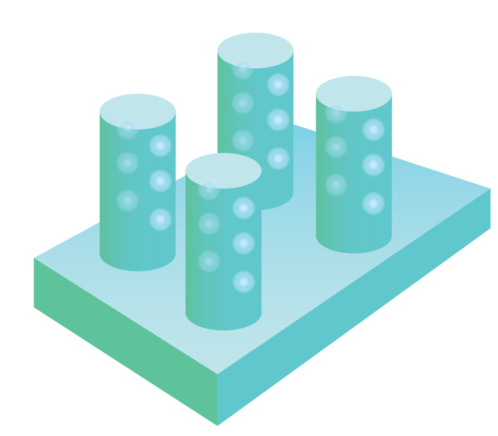

An array of completed nanowires. Irregularities are caused by surface impurities that scatter plasma ions during etching. Tapering is due to inhomogeneity in the plasma applied to the surface of the diamond.



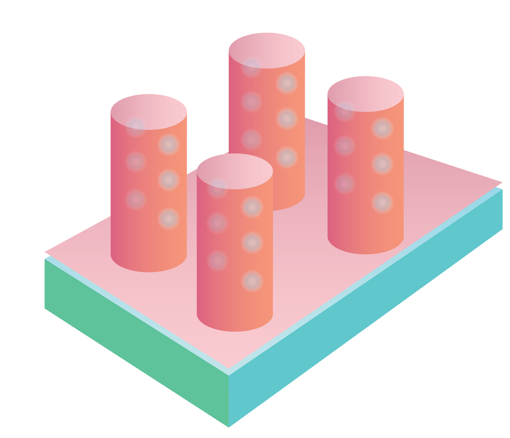
**electron beam lithography:** draw glass patterns by exposing suspended silicates to high-energy electrons.



**reactive ion etching:** apply a strong electric field to a high-energy plasma in order to etch in one direction.



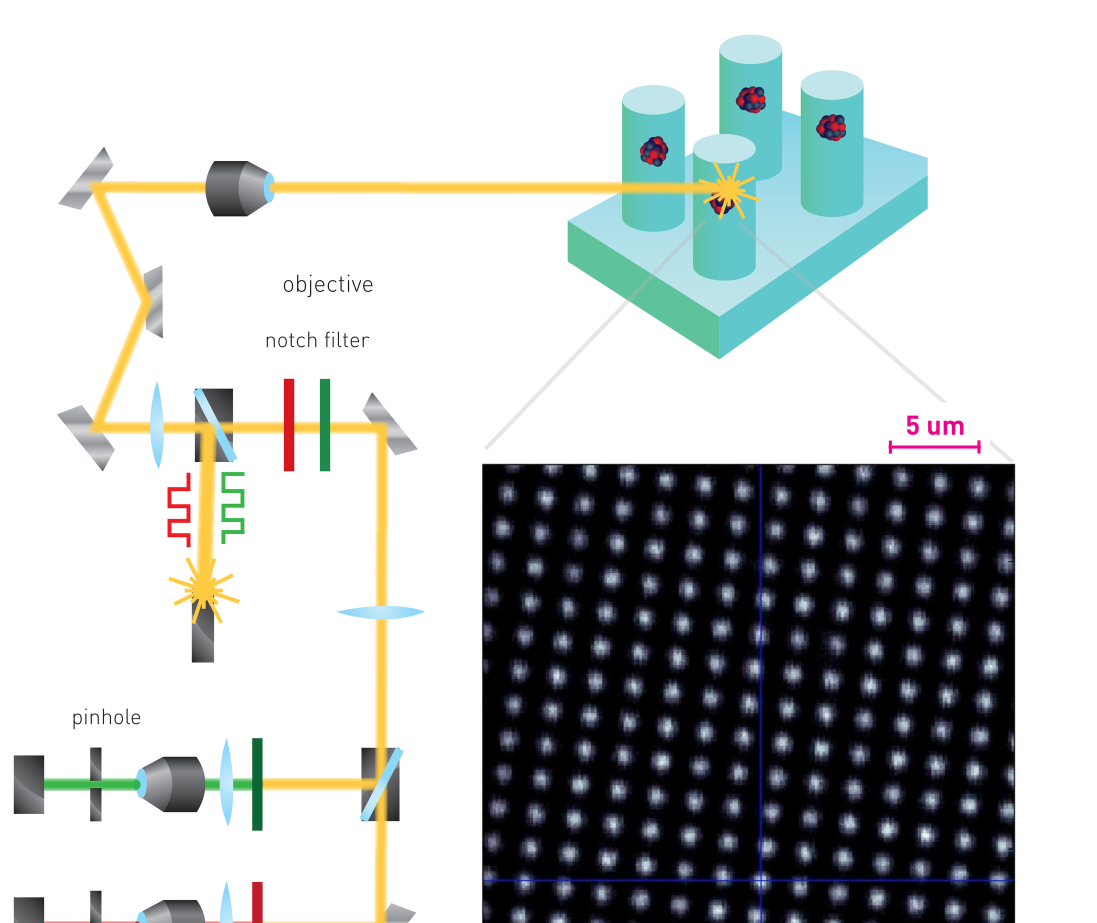
**ion implantation/annealing:** expose the wires to a beam of ions, and then heat at a high temperature.



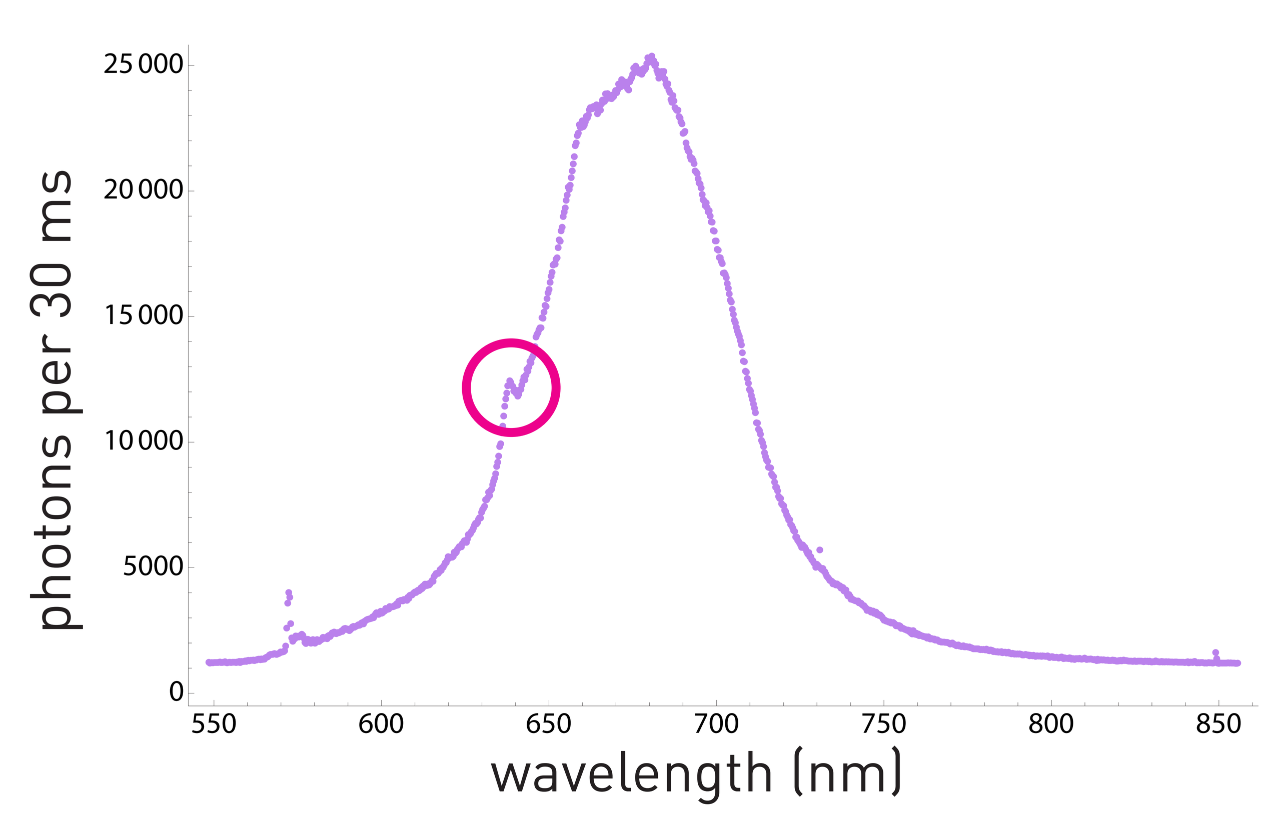
**surface treatment:** dope with additional implanted ions or a surface coating

## Results

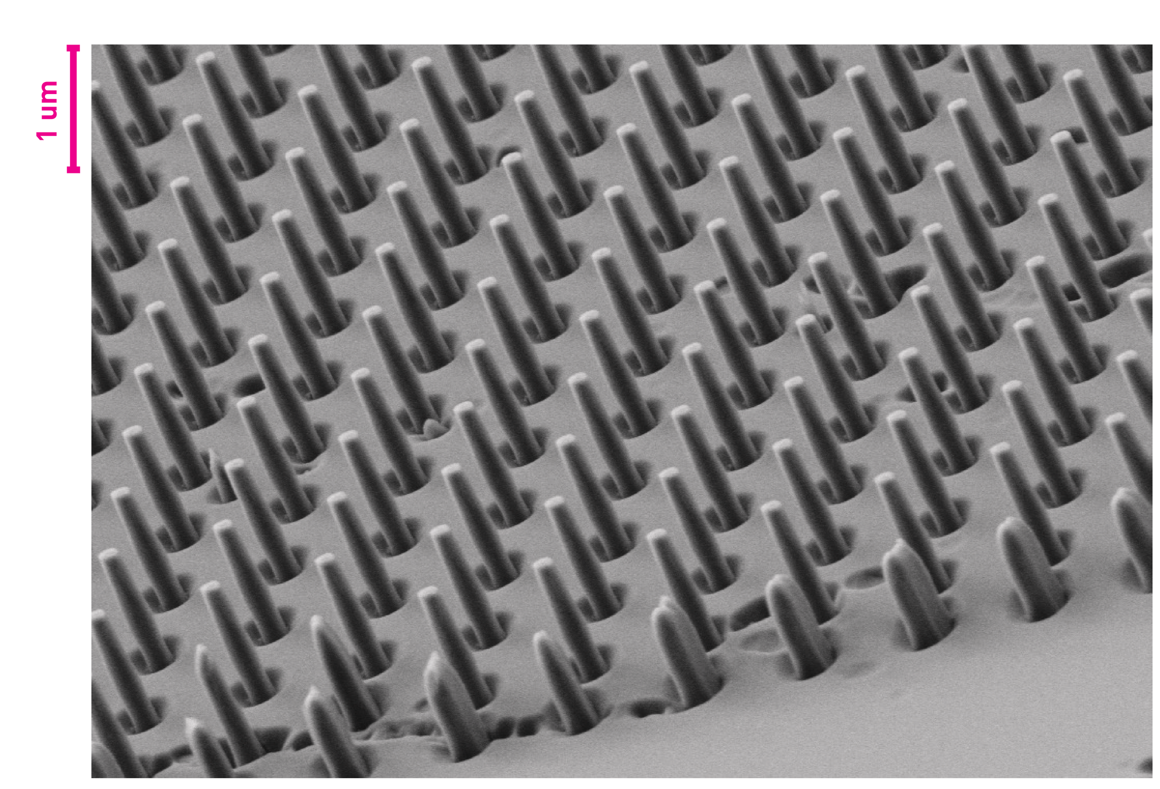
Nanowires that have been exposed to different implantation conditions fluoresce at different intensities and with different relative amounts of NV-.



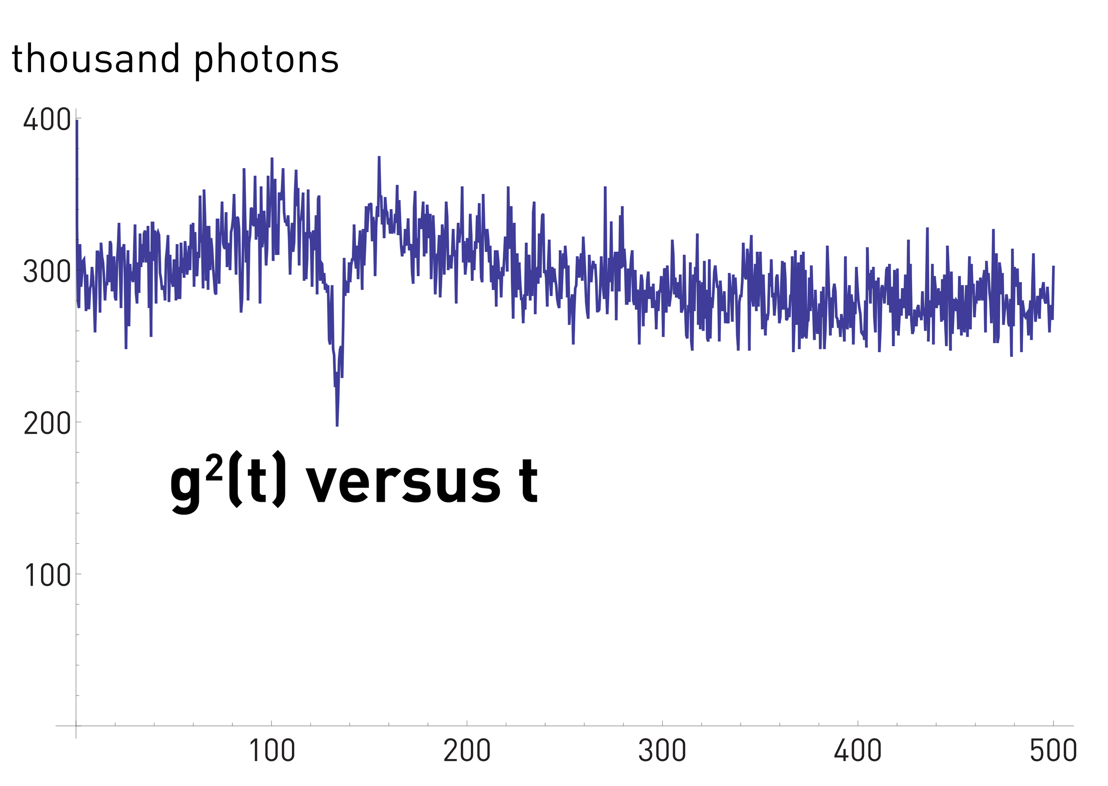

A confocal microscope precisely measures the fluorescence of NV centers, indicating their charge state. A green laser is focused onto a single nanowire, and the resulting red fluorescence travels back along the input path and is filtered out with a color filter. Scanning the beam across the surface generates an image of the nanowires (inset).



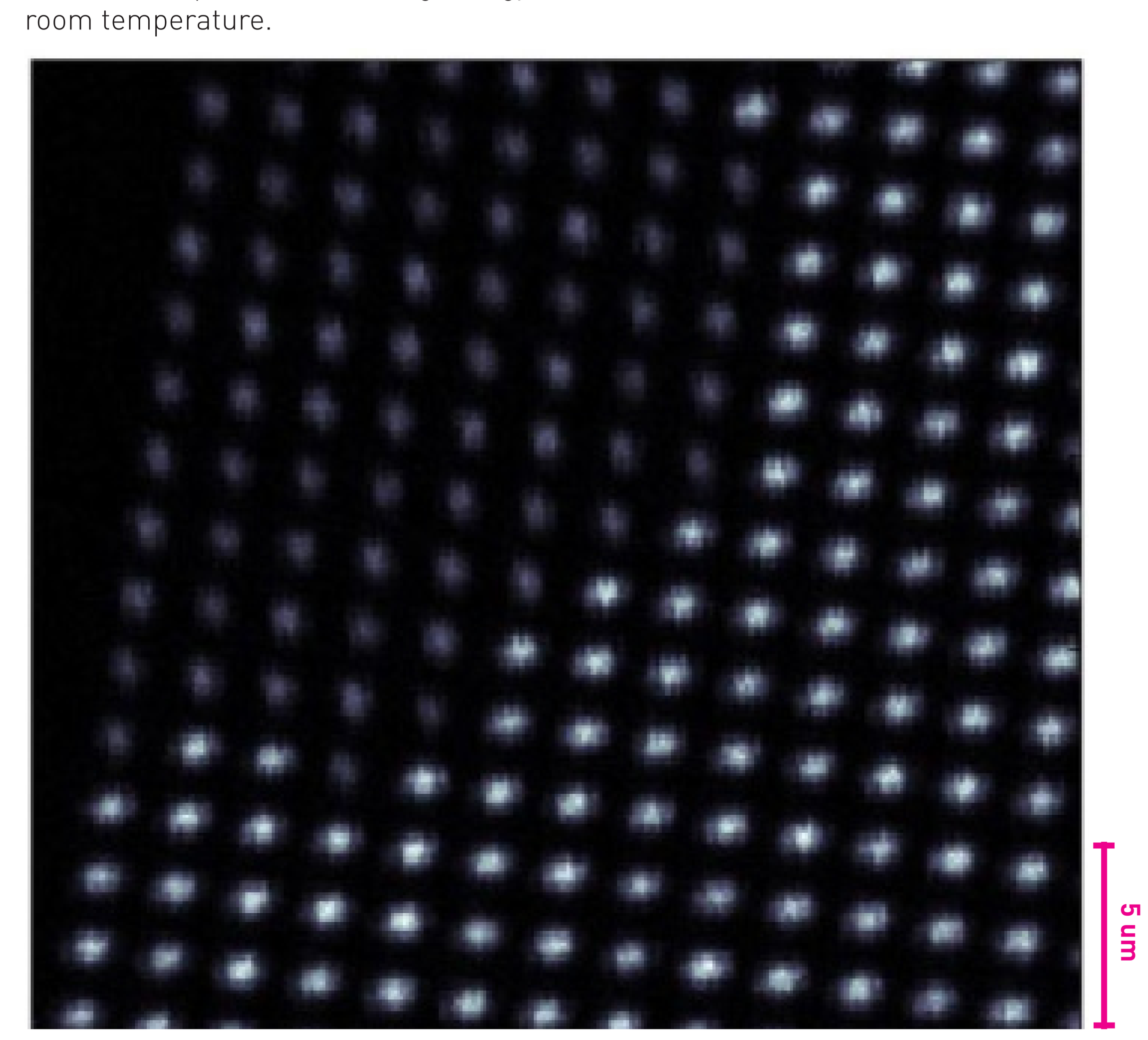

The emission spectrum of a single nanowire shows a small peak at 637 nm, indicative of red NV- fluorescence. The large, wide peak around 675 nm is due to phonons releasing energy when measurements are made at room temperature.




Nanowires can also be coated with a thin layer of conformal insulator (22 nm $Al_2O_3$ is shown here), which serves a similar function to ion implantation by donating extra electrons to the diamond conduction band near the surface.




A histogram of the times between consecutive photons arriving at each of two detectors. If both detectors are connected to the output of a single NV center but separated by a beam splitter, then the shape of the histogram shows the anticorrelation between the emission of consecutive photons over different time scales. The graph is used to determine how many NV centers are in a given nanowire.




Wires that were covered during the nitrogen implantation step (top left) do not fluoresce as brightly as identical wires that were exposed to the nitrogen (bottom right). This suggests that implantation generates additional NV centers.

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