Deterministic Creation of Closely-Spaced Single NV Centers in Diamond

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Spin systems in solids- have been intensively investigated as an outstanding pathway towards quantum information processing. One of the advantages of solid-state spintronics is the potential for application of conventional semiconductor nanofabrication techniques to (a) produce spin qubits, and (b) control their relative positioning down to the nanoscale. The negatively charged nitrogen vacancy (NV^-) center in diamond has attracted significant interest in recent years due to its optically addressable spin, convenient spin state initiation, manipulation and read-out and its long coherence time. In order for this type of system to be viable for quantum information technology it is critical to develop a procedure to deterministically engineer single artificial NV centers with nanometer-scale control over position and to integrate them within an optoelectronic device. In recent years various techniques for the creation of single NV centers have been developed,[1,2] specifically by implantation of nitrogen ions through lithographically patterned masks of different materials. However in these approaches, no attempt was made to produce closely spaced NV centers that would support the entanglement of neighboring qubits. This is a crucial requirement for the implementation of any quantum information processing device and is a key challenge in this field.

In this work, we present a fabrication technique aimed at creating arrays of single artificial NV centers spaced apart by ~ 30 – 40 nm or less, sufficient to enable coupling between their spins. Ultra-high resolution electron-beam lithography in combination with highly directional RIE is used to create apertures in a 30 nm-thick gold mask deposited directly onto an ultra-pure CVD-grown diamond substrate. This gold film carrying closely spaced apertures, ~ 10 nm in diameter (Fig. 1), serves as a mask for the broad-beam implantation of single nitrogen impurities. A final annealing allows the diffusion of vacancies in the crystal and the formation of negatively charged NV^- centers. The key improvement in our approach is the use of a very thin mask, which permits the formation of nanoscale apertures with a low aspect ratio and in close proximity to one another, enabling the achievement of high resolution and fine pitch. The employment of a high density, high atomic mass material, such as gold, ensures that even a 30 nm film presents excellent masking contrast for the implantation of < 10 KeV nitrogen ions. Figure 2 shows preliminary photoluminescence data from arrays of implanted NV centers. From a thorough analysis of the implanted spin qubits we expect to observe evidence of deterministic two-qubit entanglement, an important step towards the implementation of a quantum processor.

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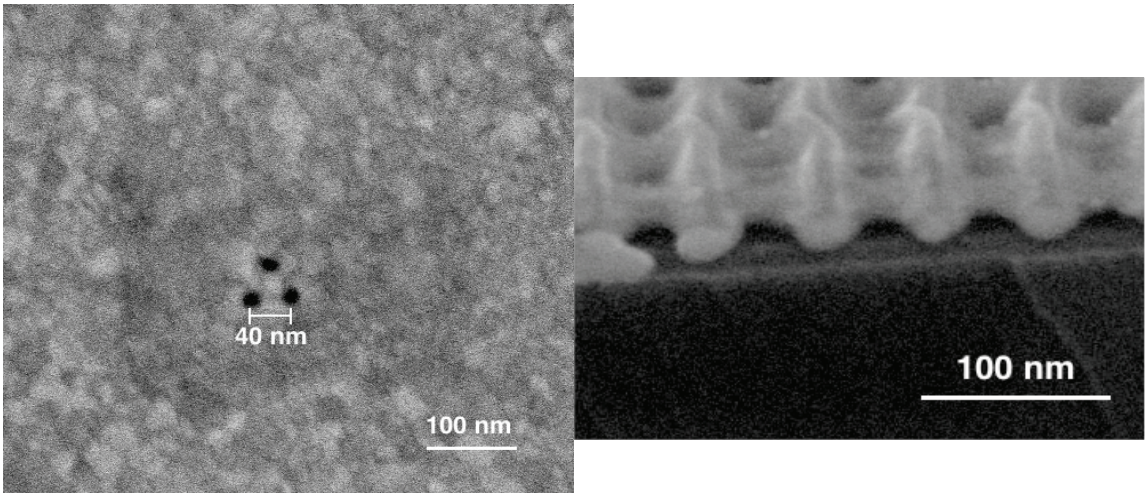

Figure 1: Realization of state-of-the-art apertures in a 30 nmthick gold film, constituting the mask for the broad-beam implantation of nitrogen ions into the underlying high-purity diamond substrate. (Right) Cross-sectional view of a 2D array of apertures formed in the gold mask.

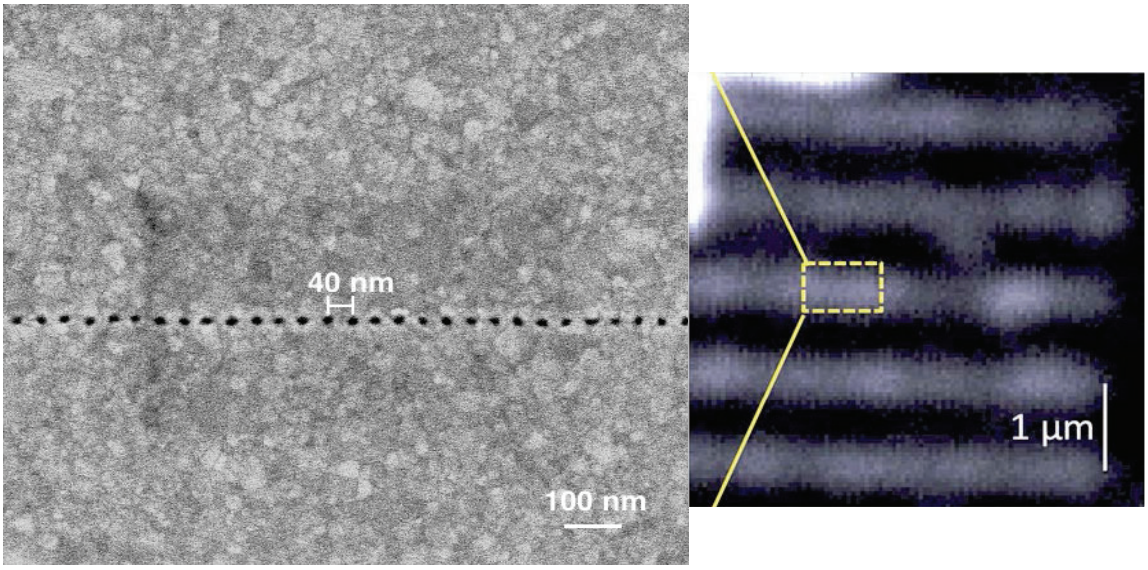

Figure 2: A chain of 10 nm-wide apertures spaced by 40 nm in the gold hard mask (left). Photoluminescence signal from negatively charged NV^- centers in diamond in an array of 40 nm-pitch chains (right).