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Fabrication of quantum emitters in aluminum nitride by Al-ion implantation and thermal annealing

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ABSTRACT

Single-photon emitters (SPEs) within wide-bandgap materials represent an appealing platform for the development of single-photon sources operating at room temperatures. Group III-nitrides have previously been shown to host efficient SPEs, which are attributed to deep energy levels within the large bandgap of the material, in a configuration that is similar to extensively investigated color centers in diamond. Anti-bunched emission from defect centers within gallium nitride and aluminum nitride (AlN) have been recently demonstrated. While such emitters are particularly interesting due to the compatibility of III-nitrides with cleanroom processes, the nature of such defects and the optimal conditions for forming them are not fully understood. Here, we investigate Al implantation on a commercial AlN epilayer through subsequent steps of thermal annealing and confocal microscopy measurements. We observe a fluence-dependent increase in the density of the emitters, resulting in the creation of ensembles at the maximum implantation fluence. Annealing at 600 °C results in the optimal yield in SPEs formation at the maximum fluence, while a significant reduction in SPE density is observed at lower fluences. These findings suggest that the mechanism of vacancy formation plays a key role in the creation of the emitters and open enticing perspectives in the defect engineering of SPEs in solid state.

Single-photon emitters (SPEs) in wide-bandgap semiconductors are promising building blocks for quantum technologies, including quantum sensing, optical quantum computing, and quantum communication.[1–3] Quantum emitters within solid-state host materials have steadily gained relevance in the last two decades. Alongside single-photon emission in quantum dots,[4] the experimental demonstration of anti-bunched emission from color centers in diamond[5] led to a vibrant scientific field focused on characterization, manipulation, and fabrication of defect systems in wide-bandgap semiconductors.[6–8] With the advancements in ion implantation technology regarding deterministic single-ion doping and nanoscale placement precision,[9–12] along with the substantial progresses in material synthesis and development in terms of controlled and selective chemical vapor deposition,[13–15] it became possible to identify and develop optically active defects with stable and efficient single-photon emission, that in several instances is correlated with their (highly coherent) spin properties. To date, a multitude of single-photon emitters in wideband-gap semiconductors have been reported, both in the visible and in the infrared spectral regions.[16–19] The two most widely investigated materials in this field are diamond[20–24] and silicon carbide (SiC).[16,25–27] Nonetheless, remarkable properties have been also demonstrated in other materials, such as silicon (Si),[28–30] gallium nitride (GaN),[17,31,32] hexagonal boron nitride (hBN),[33–35] and aluminum nitride (AlN).[36–38] Aluminum nitride (AlN) is a wide-bandgap semiconductor ($E_g = 6.03$ eV) with a refractive index of $\sim$2.15 at $\lambda = 650$ nm. It is well known and employed as a piezoelectric material, a durable ceramic, and the ideal buffer layer for GaN growth,[39] making it an appealing semiconductor for the implementation of high-power electronics and next-generation