Photodynamics and Enhanced Photon Emission in Aluminum Nitride Quantum Emitters

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Wide bandgap semiconductors often contain defects that exhibit luminesce at room temperature. While much attention has been given to vacancy-ion complexes in diamond, such as SiV and NV-, which possess internal spin-sub-levels useful for various applications like sensing external fields, hosting spin qubits, or generating single photons, the presence of intersystem crossing in their energy levels limits their saturated intensity. In contrast, point-like emitters in the commercially important $Al_xGa_{1-x}N$ semiconductors have received much less scrutiny, but have been found in as-grown epilayers [1] and created using ion-implantation [2]. These emitters exhibit antibunched light emission at room temperature and it was recently shown that defects in GaN can also host single spin qubits amenable to optical detected magnetic resonance spectroscopy [3].

In this study we report on the photodynamics of a class of emitters identified in commercial AlN-on-sapphire wafers. At room temperature their spectra are dominated by a broad phonon side-band, but in some it is possible to identify a zero phonon line near 600 nm (Fig. 1b). All emitters display linear absorption and emission dipoles, which are not parallel, and are not well aligned to the crystallographic axes [4]. Under increasing CW laser excitation at 532 nm we observe saturated rates over an order of magnitude greater than a single NV^- used as a standard candle to calibrate our detection system, Fig. 1c. Our investigation reveals the intensity and photon emission dynamics, under pulsed and CW excitation, are governed by multiple dark 'shelving states', for example resulting in multiple exponential decay constants seen in the autocorrelations of Fig. 1d [5].

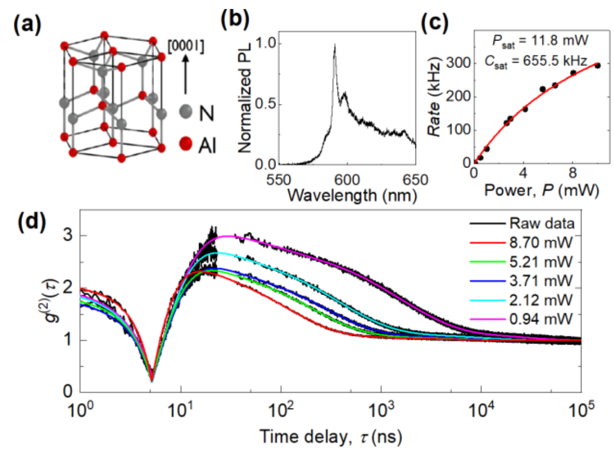

Fig.1. Quantum emitters in AlN (a) Wurtzite lattice structure of AlN, (b) emission spectrum at room temperature, (c) saturation under CW 532 nm excitation, (d) power dependence of the autocorrelation reveals *reduced* bunching at high intensity.

We present a model which reveals laser-driven depopulation of the shelving states dominates at high power, boosting the saturated photon detection rate in as-grown material. Leveraging established manufacturing techniques developed for AlGaN solid state lighting and transistors we aim to integrate these emitters in photonic resonators to further increase efficiency. Our ongoing efforts involve the development of crystallographically vertical and smooth photonic resonators with facet-selective etchants to further enhance the photon collection rate.

References

[1] S. G. Bishop *et al*, ACS Photonics 7 (7), 1636-1641 (2020)

[2] E. Nieto Hernández *et al*. Appl. Phys. Lett. 124, 124003 (2024).

[2] J. Luo *et al*. Nature Materials. 10.1038/s41563-024-01803-5 (2024).

[3] J. K. Cannon *et al*, Appl. Phys. Lett. 122, 172104 (2023).

[4] Y. Guo *et al*, https://arxiv.org/abs/2310.18190 (2023).