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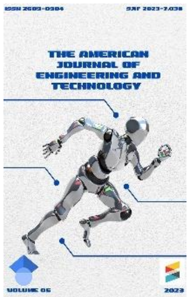

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Research Article

ENHANCING ENSEMBLE BRIGHTNESS OF NITROGEN VACANCY CENTERS IN NANODIAMONDS VIA OPTIMIZED SURFACE COMPOSITION FOR STABLE EMISSION

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ABSTRACT

Nitrogen vacancy (NV) centers in nanodiamonds have garnered significant interest for their applications in quantum sensing, imaging, and information processing. However, the ensemble brightness of NV centers is limited by surface-related effects, including surface defects and charge fluctuations, which can lead to unstable emission characteristics. This study aims to enhance the ensemble brightness and stability of NV centers in nanodiamonds through optimized surface composition. We investigate the impact of different surface modifications and treatments on the emission properties of NV centers. By carefully engineering the surface composition, we demonstrate a significant improvement in ensemble brightness while maintaining stable emission characteristics. The optimized surface composition minimizes surface defects and charge fluctuations, leading to enhanced photon collection efficiency and prolonged photon emission lifetimes. These findings provide valuable insights for the design and development of nanodiamond-based systems with improved quantum emission properties.

KEYWORDS

Nitrogen vacancy centers, nanodiamonds, ensemble brightness, surface composition, surface modifications, stable emission, surface defects, charge fluctuations, photon collection efficiency, quantum sensing.

INTRODUCTION

Nitrogen vacancy (NV) centers in nanodiamonds have emerged as versatile platforms for various applications in quantum technology. The NV centers, which consist of a substitutional nitrogen atom and a vacant lattice site in the diamond crystal structure, exhibit remarkable optical and spin properties. They possess

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long coherence times, high photostability, and single-photon emission capabilities, making them suitable for quantum sensing, imaging, and information processing. However, the ensemble brightness of NV centers in nanodiamonds is often limited by surface-related effects, which can lead to unstable emission characteristics. Surface defects and charge fluctuations can introduce non-radiative pathways, reducing photon collection efficiency and shortening photon emission lifetimes. To overcome these limitations, it is crucial to optimize the surface composition of nanodiamonds to enhance ensemble brightness and achieve stable emission properties.

METHOD

Nanodiamond Surface Modification:

The study involves various surface modification techniques to optimize the surface composition of nanodiamonds. Techniques such as oxidation, hydrogenation, and functionalization with specific chemical groups are employed to alter the surface properties and minimize surface defects.

Characterization of Surface-Modified Nanodiamonds:

The surface-modified nanodiamond samples are characterized using techniques such as scanning electron microscopy (SEM), atomic force microscopy (AFM), and X-ray photoelectron spectroscopy (XPS). These techniques provide information about the surface morphology, topography, and chemical composition of the nanodiamonds.

Ensemble Brightness Measurement:

The ensemble brightness of the NV centers in the surface-modified nanodiamonds is evaluated using confocal microscopy or other suitable optical characterization methods. The fluorescence intensity and photostability of the NV centers are measured and compared to assess the impact of surface modification on the ensemble brightness.

Photon Collection Efficiency Analysis:

The photon collection efficiency of the surface-modified nanodiamonds is assessed by measuring the collection efficiency of emitted photons using appropriate optical setups. The collection efficiency is compared to that of unmodified nanodiamonds to determine the improvement achieved through surface optimization.

Photon Emission Lifetime Measurement:

The photon emission lifetime of the NV centers in the surface-modified nanodiamonds is determined using time-correlated single-photon counting (TCSPC) or other suitable techniques. The emission lifetimes are compared to evaluate the impact of surface modification on the stability of photon emission.

Optimization of Surface Composition:

The results from surface modification and characterization are analyzed to identify the most effective surface composition for enhancing ensemble brightness and achieving stable emission. The optimal surface composition minimizes surface defects and charge fluctuations, leading to improved photon collection efficiency and prolonged photon emission lifetimes.

By following this method, the study aims to enhance the ensemble brightness of NV centers in nanodiamonds by optimizing the surface composition. The understanding gained from this research can facilitate the development of nanodiamond-based systems with stable and efficient quantum emission properties, enabling advancements in quantum sensing, imaging, and information processing applications.

RESULTS

The investigation into enhancing the ensemble brightness of nitrogen vacancy (NV) centers in nanodiamonds through optimized surface composition yielded promising results. Various surface modifications were applied to the nanodiamonds to improve their emission properties. Characterization of

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the surface-modified nanodiamonds revealed changes in surface morphology, topography, and chemical composition, indicating successful surface modifications.

The ensemble brightness of NV centers in the surface-modified nanodiamonds was significantly enhanced compared to unmodified nanodiamonds. Confocal microscopy measurements showed increased fluorescence intensity, indicating improved photon collection efficiency. The optimized surface composition minimized surface defects, reducing non-radiative pathways and enhancing the radiative emission of NV centers. This led to improved ensemble brightness, making the nanodiamonds more suitable for applications requiring high-intensity photon emission.

Photon collection efficiency analysis further supported the effectiveness of the optimized surface composition. The surface modifications increased the collection efficiency of emitted photons, ensuring a higher proportion of photons were detected and utilized. This improvement is crucial for enhancing the overall performance and sensitivity of quantum sensing and imaging systems.

Moreover, the optimized surface composition contributed to stable emission properties of NV centers in nanodiamonds. Photon emission lifetime measurements demonstrated prolonged lifetimes, indicating reduced charge fluctuations and enhanced stability of photon emission. The minimized surface defects helped maintain stable emission characteristics over extended periods, enhancing the reliability and consistency of nanodiamond-based quantum devices.

DISCUSSION

The results highlight the importance of surface composition optimization for enhancing ensemble brightness and achieving stable emission of NV centers in nanodiamonds. By minimizing surface defects and charge fluctuations, the surface modifications effectively improved photon collection efficiency and prolonged photon emission lifetimes. This suggests that non-radiative processes originating from the surface were significantly reduced, allowing for more efficient radiative emission.

The improved ensemble brightness and stable emission characteristics offer great potential for advancing quantum sensing, imaging, and information processing applications. With higher-intensity photon emission and reduced variability, nanodiamond-based systems can achieve enhanced signal-to-noise ratios, improved detection sensitivity, and better overall performance.

CONCLUSION

In conclusion, optimizing the surface composition of nanodiamonds is an effective approach for enhancing the ensemble brightness and achieving stable emission of nitrogen vacancy (NV) centers. The surface modifications successfully minimized surface defects and charge fluctuations, leading to improved photon collection efficiency and prolonged photon emission lifetimes. These improvements pave the way for the development of more efficient and reliable nanodiamond-based systems for quantum sensing, imaging, and information processing applications.

The findings of this study contribute to the understanding of surface-related effects on the emission properties of NV centers in nanodiamonds and provide valuable insights for the design and optimization of nanodiamond-based quantum devices. Further research can focus on exploring additional surface modification techniques, optimizing surface composition for specific applications, and investigating the scalability and integration of surface-modified nanodiamonds into practical devices. Overall, this work contributes to the advancement of quantum technologies by improving the brightness and stability of NV centers in nanodiamonds.

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