Fluorescent diamond needles in research and applications

Sergei Malykhin
Department of Physics and Mathematics, University of Eastern Finland, Joensuu, Finland
sergeim@uef.fi

Diamond, known for its exceptional hardness and optical clarity, is also highly valued for advanced technological applications due to its unique physical and chemical properties. Its excellent thermal conductivity, electrical insulation, and resistance to radiation damage make it indispensable in high-performance applications. In electronics, diamond enhances high-power and high-frequency devices with its wide bandgap, improving efficiency and durability. Its transparency to a broad spectrum of light makes it ideal for advanced optics and photonics, including high-power laser systems. Additionally, diamond's biocompatibility and chemical inertness are beneficial in biomedical applications, such as implantable medical devices and drug delivery systems.

Fluorescent diamonds exhibit fluorescence due to color centers in their crystal lattice, which absorb and emit light, resulting in visible fluorescence under certain conditions. These properties make fluorescent diamonds valuable for various advanced technological applications. They are used in bioimaging and medical diagnostics, where their biocompatibility and stable fluorescence allow for precise tracking and imaging of biological processes. The versatility of fluorescent diamonds with color centers continues to drive innovation in multiple scientific and technological fields.

Among diamond color centers, those exhibiting optically detected magnetic resonance (ODMR), such as NV [1], TR12 [2], and ST1 [3] centers, are particularly interesting. These centers' electronic spin states can be manipulated and read using optical methods. In quantum computing, they serve as stable qubits at room temperature, aiding the development of quantum processors [4]. In quantum sensing, they allow high-resolution detection of magnetic fields, electric fields and temperature [5].

Bulk diamonds, nanodiamonds, and diamond arrays represent different forms of diamond material, each with unique properties and applications across various technological fields. Bulk diamonds, prized for their optical purity and crystal quality, are ideal for advanced diamond-based optics. Nanodiamonds, with their high surface area, biocompatibility, and functionalization potential, are suitable for drug delivery and bioimaging [6]. Diamond arrays, consisting of patterned or ordered structures, leverage diamond's properties at micro and nanoscale, making them useful in quantum computing for hosting many qubits and in sensing technologies for high spatial resolution and sensitivity.

This work focuses on diamond needles, or single crystal diamond needles (SCDNs) [7], an alternative form of diamond. SCDNs are promising for both scientific research and technological applications. Their sharp tips and robustness make them ideal for high-resolution scanning probe microscopy. In quantum technology, SCDNs with embedded color centers [8], like NV centers, can serve as highly sensitive quantum sensors, capable of detecting magnetic fields, electric fields, and temperature variations with high precision. Their geometry is promising for efficient interaction with external quantum systems, suitable for quantum communication and computation. Additionally, their biocompatibility opens applications in medical diagnostics and treatment. The unique properties of diamond needles make them a powerful tool across various advanced technological and research domains.

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