Luminescent Thermometers Based on Novel Narrowband and Spectrally Tunable Emitters in Nanodiamonds

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Luminescent nanothermometry has emerged as a transformative tool for high-precision temperature sensing at micro- and nanoscale levels in fields of biology, microelectronics, and catalysis [1]. Previously, we introduced a groundbreaking approach for nanoscale temperature control using a Diamond Heater Thermometer (DHT). Its configuration is based on a glass microcapillary integrated with nanodiamonds containing silicon-vacancy (SiV) centers. By utilizing the temperature-dependent spectral shift of the zero-phonon line of SiV centers, DHT proved its efficiency in mapping nanoscale temperature gradients near micro-heaters in aqueous solutions [2], monitoring mitochondrial heat production during bioenergetic processes [3], thermal triggering of calcium events [4] and rapid driving electrophysiological properties in living cells [5].

Recently, luminescence spectra of nanodiamonds synthesized from hydrocarbons and doped with nitrogen revealed numerous narrow (<1 nm) lines of unknown origin across a wide spectral range from 500 nm to 800 nm. It was established that these lines are associated with radiative recombination of donor-acceptor pairs (DAP), formed by donor nitrogen impurities in the diamond lattice and a 2D acceptor layer on its surface [6]. The new DAP fluorescence offers several advantages over SiV luminescence for use in diamond nanothermometry: (1) the linewidth of DAP luminescence is an order of magnitude narrower than that of SiV fluorescence, (2) the luminescence intensity of a single DAP is an order of magnitude higher than that of a single SiV center, and (3) DAP emission is tunable across a broad range of 500–800 nm, whereas SiV centers emit only at 738 nm. In this work, we study the thermal sensitivity and the noise floor level of a DAP-based thermometer in HPHT-nanodiamonds as small as 50 nm. It was found that the sensitivity of DAP luminescence across temperature ranges of 20–120°C is 0.04 and 0.05 nm/°C for spectral position and linewidth, respectively. While the sensitivity exhibits slight variations between individual particles, it remains independent of the spectral region. For both spectral strategies, a typical thermal noise floor was quantified to be 90 $\mathrm{mK} \cdot \mathrm{Hz}^{-1/2}$, enabling precise temperature determination via both emission peak position and linewidth with an uncertainty limited only with detector noise. DAP recombinant emitters redefine the capabilities of diamond-based luminescent nanothermometry, offering a compelling alternative to color centers based methods and broadening the scope of temperature sensing and control at the nanoscale.

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