Thermal Effects on Optical Properties of Color Centers in Diamond and Silicon Carbide

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Defect-induced color centers in solids are promising candidates for applications in quantum information science. The optical properties of these color centers are primarily determined by their zero-phonon lines (ZPLs). Besides nitrogen-vacancy (NV) centers, group-IV (Si, Ge, Sn, and Pb) color centers have attracted attention due to their enhanced emission into the ZPL and high single-photon emission rate. For example, silicon vacancy (SiV) color centers in diamond feature sharp and strong ZPLs. These ZPL emissions are strongly dependent on the temperature. In this presentation, I will discuss two examples of thermal effects on optical properties of color centers in diamond [1] and silicon carbide (SiC) [2].

We measured ZPL emissions of SiV color centers implanted using ion beams and studied the temperature dependence of ZPL. At low temperatures, the photoluminescence (PL) spectrum shows two resonances along with a phonon side band (PSB). As the temperature increases, the spectrum broadens and has an energy shift. The temperature dependence measurements of the ZPL center position reveal a red shift from 50 K to room temperature, while the center position shifts slightly to the blue as the temperature increases from 4 to 50 K. The red shift from 50 K to room temperature is attributed to the thermal expansion of the host lattice in diamond, while the blue shift below 50 K indicates an abnormal negative thermal expansion of the host lattice. The results can be modeled by a combination of the bulk thermal expansion and the electron-phonon interaction.

In another study of SiV color centers in SiC, we observed the ZPL emissions can be affected by the local temperature variation due to the heating by the excitation laser. The effects of laser-induced heating are manifested as the decrease in the peak height, redshift of the emission energy, and broadening of the linewidth. By using Varshini equation [3] to correlate the ZPL center energy with the sample temperature, we can quantify the temperature variation induced by laser-induced heating and develop a thermal conducting model to fit the measured dynamics of laser heating effects over time. The result highlights the importance of accounting for local heating by the excitation laser when investigating the optical properties of color centers in solids. Conversely, the sharp ZPL can be used as a local temperature probe for localized temperature monitoring in color center-based devices.

References

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