In-Situ Temperature Measurement of Diamond Devices using NV Centers

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Diamond semiconductor devices are a promising platform for next generation low-loss power electronics. High thermal conductive diamond is expected to realize a compact cooling system and high-temperature operation. Because high current passes through power devices, in-situ monitoring of the device temperature provides important information to develop such system. In this study, we performed temperature measurements of operating diamond devices using nitrogen-vacancy (NV) centers formed close to the devices. We have so far demonstrated sensing of the internal electric-field in diamond devices by measuring a split of magnetic resonance frequencies of NV centers [1]. Here, the temperature variation of the device was measured by observing the zero-field splitting (D_{GS}) of the NV centers.

Vertical diamond p-i-n diodes were fabricated on a (111) p-type diamond substrate. Ensemble NV centers were fabricated in an intrinsic layer (5 μm) by ion implantation with a projected depth of approximately 350 nm (Fig. 1a). While the forward current flows through a device, the temperature measurements were performed at NV centers close to the device, 30 and 60 μm away from the cathode electrode. The temperature was measured by observing optically detected magnetic resonance (ODMR) spectra (Fig. 1b). When increasing the forward current from 0 to 5 mA, the center of the two dips (D_{GS}) clearly shifts to lower microwave frequencies, indicating the rise of the temperature. The temperature increase (ΔT) was estimated by using the relation, $\Delta D_{GS}/\Delta T$ = -74.3 kHz/K [2,3], as shown in Fig. 1c. ΔT shows a linear dependence of the forward current and reaches 16 K at a forward current of 5 mA. Importantly, we obtained a higher slope of 3.1 K/mA at closer NVs (30 μm from the device) than 2.8 K/mA at 60 μm. Thus, we expect temperature mapping by using CCD to see detailed ΔT distribution.

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References: [1] T. Iwasaki et al., ACS Nano, accepted, DOI:10.1021/acsnano.6b04460. [2] V. Acosta *et.al.* Phys. Rev. Lett. 104, 070801 (2010). [3] M. Doherty *et al.* Phys. Rev. B 90, 041201 (2014).

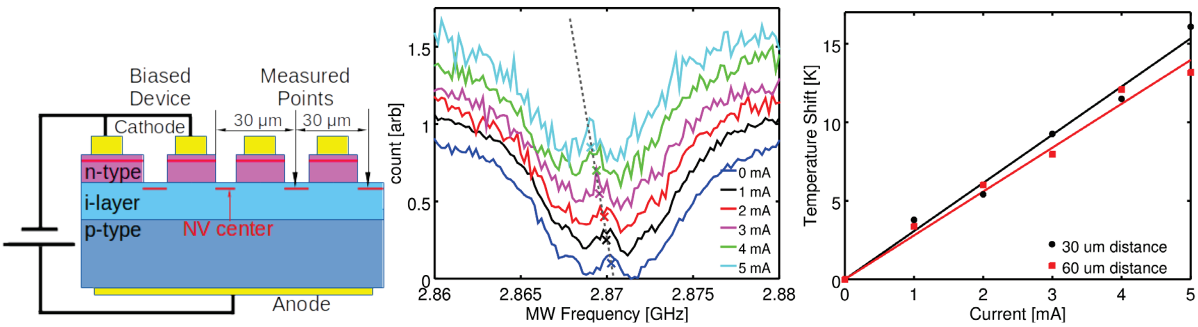

Figure 1. (a) Schematic of device structure and measurement configuration. (b) Measured ODMR spectra with forward currents (c) Estimated temperature at different positions, 30 and 60 μm away from the device.