

Observation of superconducting quantum vortices in YBCO using diamond quantum sensors

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Superconducting vortices are characteristic excitations of type-II superconductors. In superconducting quantum computers, which are currently being actively developed toward practical applications, the presence of vortices on qubit devices can degrade the quality factor and modify the qubit Hamiltonian, thereby reducing device performance [1]. Therefore, understanding the properties and dynamics of superconducting vortices is important for improving the performance of superconducting quantum computers.

In this study, we perform magnetic-field imaging of superconducting vortices using nitrogen-vacancy (NV) centers in diamond. The resonance frequencies of NV centers shift in response to an external magnetic field, and these shifts can be optically detected, enabling wide-field magnetic-field imaging. In particular, the use of diamond with fully aligned NV axes [2] allows quantitative analysis of the magnetic-field distribution. We investigate vortices in a $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) thin-film sample. To date, vortices have been generated by cooling the sample in an external magnetic field and their spatial distribution has been imaged using NV centers [3]. We have also confirmed that vortices are driven when the external magnetic field is changed after cooling. This behavior can be explained by the Lorentz force exerted on the vortices by shielding currents induced in the superconductor [4]. Furthermore, by analyzing vortex motion in local regions before and after changing the external magnetic field, we quantitatively found that the fraction of moving vortices increases in regions with larger shielding currents.

In future work, we will investigate the relationship between the Lorentz force generated by shielding currents and the fraction of moving vortices at different temperatures. Through this analysis, we aim to evaluate the vortex pinning force in YBCO thin films and its temperature dependence.

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