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Abstract

Development of scanning NV center magnetometer probe microscope

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Introduction:

A magnetometry method for the detection of magnetic properties from an ensemble or single spin in the material has been developed. For instance, NMR (nuclear magnetic resonance), which can detect the magnetic signal from a nuclear spin, has been applied as MRI (magnetic resonance imaging) for life science and medical science. In recent years, spintronics, which utilizes not only electron charge but also electron spin, has been attracting much attention for information processing. A divergence of spin accumulation in materials called spin current is scattered by local physical interaction between magnetic momentum of electron spin and nuclear in the atom (spin-orbit coupling).

Imaging technology for these spin physics phenomena is important to understand the localized interaction in the materials. Nitrogen-vacancy (NV) center in diamond is a kind of impurity. It consists of a substitutional nitrogen atom and adjacent neighbor vacancy missing the carbon atom in the diamond crystal. NV center has shown excellent stable photon property dependent on the magnetic interaction around. A scanning magnetometer probe hosting the NV center at the apex of the probe has attracted attention from many scientific fields. It can realize magnetic field imaging at the nanoscale due to the nanoscale size of a single NV center. A nanodiamond hosting a single NV center and a diamond cantilever fabricated by lithography were mostly used. On the other hand, for improving magnetic sensitivity, and spatial resolution, the structure of the scanning probe is a crucial problem. A parabolic shape of probe structure fabrication using lithography has solved the problem. We focused on using a focused ion beam (FIB) for the fabrication method. FIB fabrication has been used to obtain atomically resolved imaging milling the probe apex to nanoscale size in an atomic force microscope (AFM) probe. For the use of NV centers hosting probe fabrication, which suffers from damage from incident Ga^+ ions, a donut-shaped milling pattern was used to reduce the damage.

Method and Result:

A (100)-oriented typeIIa diamond sample grown by chemical deposition (CVD) was used. To form NV centers in diamond, nitrogen ions were implanted with a dose of $1\times 10^{12}/cm^2$. Successively, the sample was annealed at 900 °C for 1 hour in Ar (argon) atmosphere, cleaned and oxidized by a solution of a mixture of NHO_3:H_2SO_4 = 1(10 mL):3(30 mL) at 220°C for 30 min. Then, the diamond substrate was polished to be 50 μm thick and cut into a rod shape with $35 \times 35 \times 50\ \mu m^3$ by laser cutting. Next, the diamond rod was attached to the end of the chemically etched tungsten wire of the AFM probe based on a quartz tuning fork. Finally, the diamond rod was processed using a donut-shaped pattern of FIB milling. Using this diamond NV probe, stray field imaging from a magnetic recording tape was demonstrated. However, this probe from typeIIa substrate has a deep distribution of NV centers from the diamond surface lowering the spatial resolution. To improve this, the electronic grade diamond (impurity less than 5ppb) probe was used. In FIB milling, Polyvinyl alcohol (PVA) and Pt-Pd sputtered layer was covered to avoid damage of Ga^+ ion irradiation. The FIB-fabricated diamond probe was confirmed to remain NV centers at the end of the diamond pillar. By using this electronic grade diamond probe, a magnetic domain structure was successfully imaged via fluorescence of the diamond NV probe, where the fluorescence intensity depends on the magnetic field strength and directions. This is due to the shortening of the lifetime of NV photons at the domain boundaries with high magnetic flux density.

Summary:

In this study, we demonstrated the fabrication of a scanning NV magnetometer probe with laser cutting and FIB processing. The type Ⅱa diamond probe has demonstrated imaging of stray magnetic fields in magnetic recording tape. By using the pure diamond substrate of electronic grade, more sensitive magnetic imaging on the magnetic domain structures was successfully obtained.

Keywords: NV center, focused ion beam, magnetometry, magnetic imaging, scanning probe microscopy