Design and Construction of Torque Magnetometer for Magnetic Properties Investigation

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Abstract. In this research, cantilever based torque magnetometer was designed and built for investigation of magnetic properties of materials. Torque exerted on magnetic moment of the sample was detected by the deflection and torsion of the cantilever. The laser beam deflected from the sample platform was detected by a four-quadrant photodiode detector. The system can be used to measure anisotropy axis of a permanent magnet. By using this technique, external field and magnetic dipole moment of the sample does not affect the measured anisotropy axis.

1. Introduction

Magnetic moment of magnetically anisotropic materials prefers to align in a certain direction called easy axis or anisotropy axis. Under an external magnetic field B, a torque τ exerted on the magnetic material with the magnetic moment m is given by

$$\vec{\tau} = \vec{m} \times \vec{B} \tag{1}$$

The torque can be measured in several different ways. A very simple way has been reported by Cullity [1] in which a sample on the holder rod hanging on the torsion wire. The torque generated by a magnetic field on the sample results in the twisting of the wire and hence the torque exerted on the sample is proportional to the rotation angle of the holder rod. The torque magnetometer based on silicon piezoresistive cantilevers has been reported by Willemin et al. [2]. The designed system can work in the flexion and torsion modes which are suitable for measuring a torque with respect to two axes. The cantilever torque magnetometer offers several advantages over other magnetometers especially its ultrahigh sensitivity [3, 4]. By using the vibrating sample magnetometer (VSM), anisotropy direction can be obtained by changing the field direction with respect to the sample. The measured magnetization is maximized when the field is in the direction of the anisotropy axis of the sample. However, the commercial torque magnetometer and rotatable field VSM are very expensive and take a long time to find the anisotropy axis. Our purpose here is to develop a low-cost measurement system for determining the anisotropy axis of magnetic materials.

2. Experimental

The designed torque magnetometer is shown schematically in Fig. 1 (a). A C-core electromagnet with a dc power supply (E3644A, Agilent Technologies) was used to generate the magnetic field and a Hall effect sensor (HGT-2100, Lakeshore) was used to measure the field. A two-leg cantilever was constructed by mounting 1.0 mm diameter quartz rods on the mirror and attached to the stand. In order to detect deflection and torsion of the cantilever, laser beam from the source (05-LHP-551-61, Melles Griot) is collimated and then focused onto the mirror. The reflected beam from the mirror is detected by a four-quadrant photodiode detector (PIN-SPOT-9DMI, OSI Optoelectronics) and the output from the detector is measured by a microcontroller board (Uno R3, Arduino). Performance of the system was tested by measuring anisotropy direction of $1.0\times1.0\times1.0$ mm^3 NdFeB permanent magnetic. Effect of magnitude of the external magnetic field and magnetic moment of the sample to the obtained anisotropy direction was also studied.

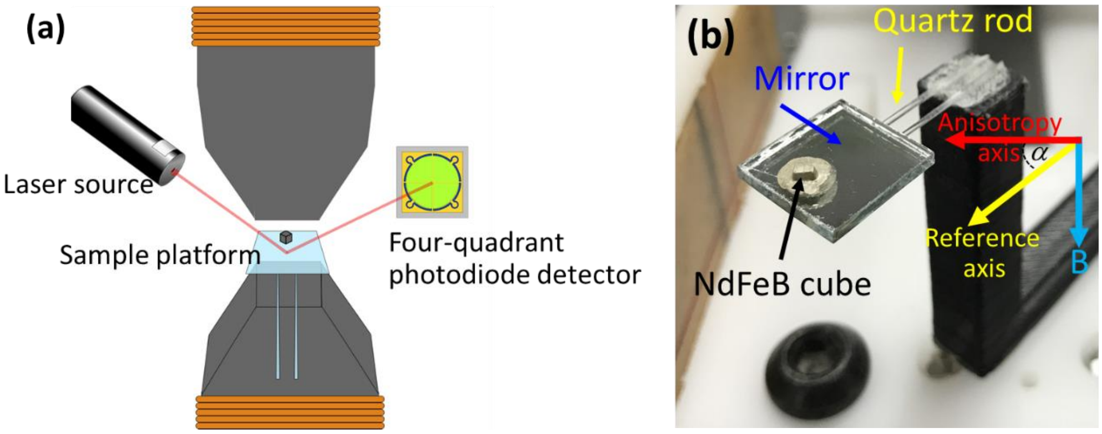

Figure 1. (a) Schematic view of the measurement system. (b) Image of the cantilever with a NdFeB cube magnet.

3. Results and discussion

Fig. 2 shows the field dependence of position of the reflected beam on the four-quadrant photodiode detector resulting from deflection and torsion of the cantilever mounted with a NdFeB cube magnet. The magnitude of x and y increase with increasing magnetic field but the ratio of y to x is rather constant. The direction of anisotropy axis of the sample with respect to reference axis is calculated from

$$\alpha_c = \tan^{-1}\left(\frac{y}{x}\right) \tag{2}$$

The variation of calculated angle decreases with increasing field from 0 to 50 mT and rather constant when magnetic field is larger than 50 mT (Fig. 3). The offset about 3.5° of α_c was observed at the magnetic field higher than 50 mT.

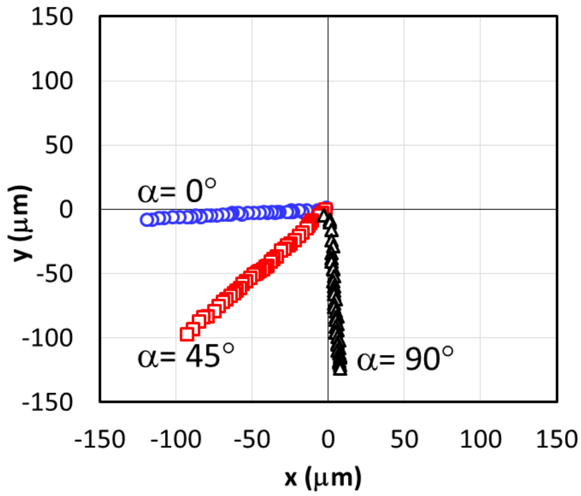

Figure 2. Variation of measuring position as a function of magnetic field for the cantilever mounted with a NdFeB cube magnet at different α.

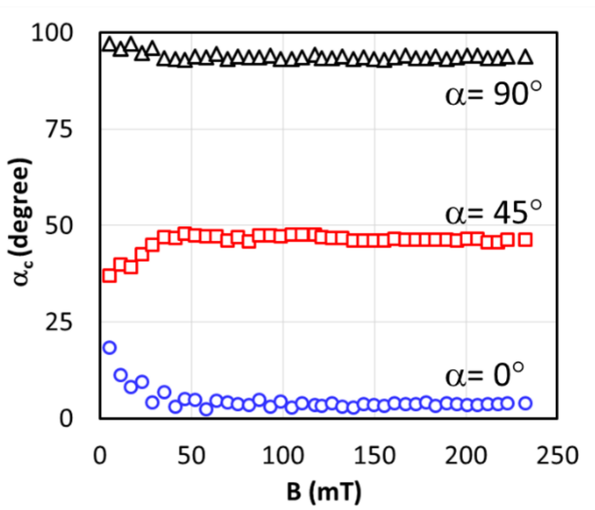

Figure 3. Field dependence of the calculated angle α_c on the external magnetic field for the cantilever mounted with a NdFeB cube magnet at different α.

Effect of magnetic moment of the sensitivity was also studied. Positions of the reflected beam for the cantilever mounted with 2 cube magnet are compared with those of the cantilever mounted with a cube magnet in Fig. 4 (a). The magnitude of both x and y increase with increasing magnetic moment but the calculated angle is rather insensitive to the magnitude of magnetic moment and mass as shown in Fig. 4 (b). The increase of magnitude of x and y by the magnetic field can be explained by equation (1). From this equation, the torque on the sample depends on magnetic field and magnetic moment. When magnetic field or magnetic moment increases, torque on the sample increases. The change in torque reflects the change in position through the reflection and torsion of the cantilever.

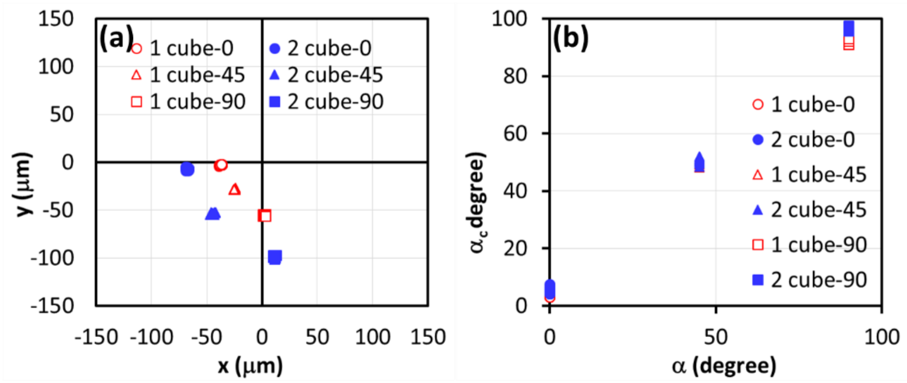

Figure 4. Position of reflected beam on the four-quadrant photodiode for the cantilever mounted with 1 and 2 pieces of NdFeB magnet at fixed magnetic field 115 mT (a) and the calculated angle (b).

The angles α_c for the NdFeB cube magnet mounted on the sample platform were calculated from the 20 measurements for the selected anisotropy directions (see Table 1). The measurements were done under magnetic field 115 mT and compensated with the offset angle 3.5°. The anisotropy axis of the sample with accuracy of 0.603% and standard deviation of 0.926° were obtained from the developed system.

Table 1. The calculated angles α_c under the magnetic field 115 mT for the NdFeB cube magnet mounted cantilever.

α (degree)	α_c (degree)	Standard deviation (degree)
0	1.7	0.794
45	46.5	0.921
90	92.6	0.853
135	136.7	0.756
180	181.8	0.715
225	227.3	0.911
270	272.5	0.813
315	316.9	0.926

4. Conclusions

The cantilever based torque magnetometer was designed and built for investigation of anisotropy direction of magnetic materials. Anisotropy direction of the cube NdFeB magnet with an accuracy of 0.603% was obtained. The main advantage of the developed system is the ability to obtain anisotropy axis in a very simple way and low-cost.

References

[1] Cullity B D 1972 Introduction to Magnetic Materials, Addison-Wesley **7** 217
[2] Willemin M, Rossel C, Brugger C, Despont M H, Rothuizen H, Vettiger P, Hofer J and Keller H 1998 J. Appl. Phys. **83** 1163
[3] Lohndorf M, Moreland J, Kabos P and Rizzo N 2000 J. Appl. Phys. **87** 5995
[4] Rigue J, Chrischon D and Carara M 2012 J. Magn. Magn. Mater. **324** 1561–1564