Novel apparatuses for pulsed field experiments: piezoelectrically driven rotator and microcantilever

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Abstract

In this paper, we present novel apparatuses for pulsed field experiments, piezoelectrically driven rotator and microcantilever. The former is useful in fine adjustment of sample position in narrow space, while the latter is a high-sensitive torquemeter applicable to samples of less than 1μg. Performance in pulsed magnetic fields is presented.

Key words: Pulsed magnetic field; Piezoelectrically driven rotator; microcantilever; magnetic torque

1. Introduction

Capacitor-driven pulsed magnetic field [1] is a powerful tool to study the magnetic, electronic, and optical properties of materials, since the maximum field strength of 40-60 T is much higher than that obtained with a superconducting solenoid. Measurement techniques such as magnetization, resistivity, cyclotron resonance, and photoluminescence have been established. However, due to experimental restrictions such as limited space, short pulse duration and large noise, experimental techniques available are still limited in pulsed field experiments. Therefore, it has been strongly desired to make it possible to perform various measurements in pulsed high magnetic fields as in steady magnetic fields.

In this paper, we present novel two techniques for use in pulsed field experiments. One is a piezoelectrically driven rotator [2] and the other is a high sensitive torquemeter with use of a microcantilever [3]. The former enables us to rotate a sample stage with high angular resolution of 0.01° in combination with a pulse magnet, and thus allows detailed angle-dependent studies of anisotropic materials. On the other hand, the latter makes it possible to detect a small change in magnetization of samples of less than 1 μg. The sensitivity of the order of $m \sim 10^{-13}$ Am^2 is superior to conventional induction methods.

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2. Piezoelectrically driven rotator

Piezoelectrically driven rotator (hereafter designated as piezo-rotator) consists of a pair of shear piezostacks and a rotating stage made of sapphire as shown in Fig. 1(a). The principle of operation is the so-called "stick and slip" motion, driven by successive saw-tooth pulses. Since the piezo-rotator is designed to fit into a narrow sample space with a diameter of 13 mm, the tilt angle of the present version is limited to $\sim \pm 10°$, but by replacing a rectangular sample stage with a circular one, 360°-rotation is realized. The advantages of the piezo-rotator are (1) controllablity with two lead wires instead of a driving shaft, (2)capability of making rotations with high angular resolution of ~0.01° in high magnetic fields, and (3)low heat dissipation of less than 100 μW during continuous rotation.

Although high angular resolution is prerequisite for the study of highly anisotropic systems such as high-T_c superconductors, it has not been so easy to rotate samples very precisely in combination with pulsed mag-

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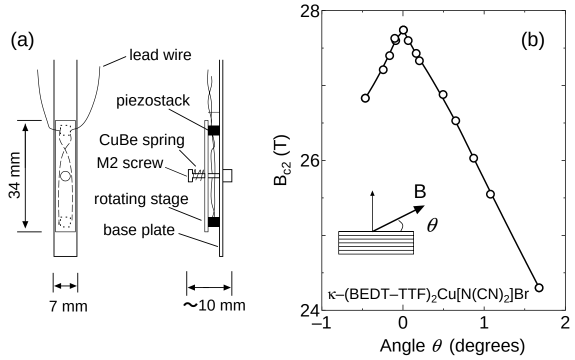

Fig. 1. (a) Schematic of a piezoelectrically driven rotator. (b) Angle dependence of the upper critical field of κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br at 4.2 K. The inset shows the definition of the tilt angle θ.

netic fields due to limited sample space. Then, we have attempted to use the piezo-rotator for this purpose, and obtained satisfactory results as shown below.

Figure 1(b) shows the angle dependence of the upper critical field B_{c2} of the layered organic superconductor κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Br with T_c of ≈12 K. The tilt angle was experimentally determined with a small Hall sensor attached to the rotating stage. The maximum angle shift during rapid field sweeps was found to be much less than 0.1°. Due to the highly anisotropic structure of this compound, the B_{c2} exhibited cusp-like behavior at around θ=0°, characteristic for two-dimensional superconductors. We found that from the present result, it was quite possible to align the magnetic field to arbitrary directions within an accuracy of better than 0.1°. In comparison with bevel gears with typical resolution of 0.5-1°, the uncertainty of the B_{c2} near θ=0° is at most 0.1 T for the piezo-rotator, while it reaches ~1 T for bevel gears, taking account of the evaluated $dB_{c2}/d\theta$ of ~2 T/°.

3. Microcantilever

A high-sensitive miniature torquemeter is developed with use of a commercial piezoresistive microcantilever for atomic force microscopy(AFM) [3]. A sample mounted at the end of a cantilever beam produces magnetic torque $\tau = M \times B$ in a magnetic field, and the resultant deflection of the beam is detected electrically. Application of cantilever magnetometry to pulsed field experiments was first carried out by Naughton *et al.* [4], but the present cantilever is more convenient, since (1) the cantilever is commercially available, and (2) the eigenfrequency of 250-300 kHz is much higher than the previous reported value of ~10 kHz, and thus the response to faster signals or shorter pulsed fields is significantly improved.

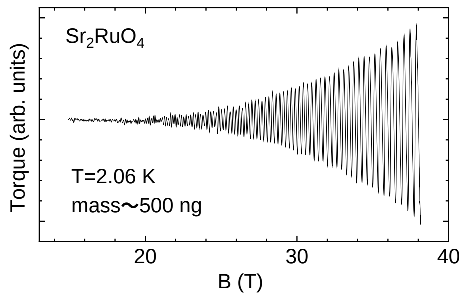

Fig. 2. Field dependence of the magnetic torque of Sr_2RuO_4 at 2 K. Magnetic field was tiled by ~30° from the c-axis.

The merit of cantilever magnetometry is also the high sensitivity compared to conventional induction methods. The resistance through a piezoresistive path is precisely measured with a Wheatstone bridge circuit, and the evaluated sensitivity was of the order of 10^{-13} Am^2 at 40 T.

Figure 2 shows the magnetic torque of the oxide superconductor Sr_2RuO_4 at 2 K as a function of magnetic field. The sample mass of ≈500 ng was evaluated from the eigenfrequency shift. The oscillatory behavior showing up at ~20 T is attributable to de Haas-van Alphen (dHvA) oscillations. The oscillation frequency of 3340 T was consistent with the previous report [5]. In addition, the envelope of the oscillations are in good agreement with that expected from the Lifshitz-Kosevich formula. We have also succeeded in dHvA measurements in pulsed fields of up to 52 T with shorter pulse duration of 16 ms. It should be noted that the eigenfrequency of the cantilever, though it was lowered from f=250 to 42 kHz due to sample load, was higher than the transient signal frequencies in these experiments. Therefore, the use of a stiff cantilever is essential for accurate measurements in pulsed high magnetic fields.

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