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Abstract

We developed piezoresistive microcantilevers for mechanically detected electron spin resonance (ESR) in the millimeter-wave region. In this article, fabrication process and device characterization of our self-sensing microcantilevers are presented. High-frequency ESR measurements of a microcrystal of paramagnetic sample is also demonstrated at multiple frequencies up to 160 GHz at liquid helium temperature. Our fabrication is based on relatively simplified processes with silicon-on-insulator (SOI) wafers and spin-on diffusion doping, thus enabling cost-effective and time-saving cantilever fabrication.

Keywords: piezoresistive effect, electron spin resonance, microcantilever, silicon-on-insulator (SOI) wafer, terahertz (THz)

1. Introduction

Mechanically detected magnetic resonance is one of most sensitive techniques to probe magnetic properties in a microscopic manner. In this technique, magnetic resonance is detected using a microcantilever as longitudinal magnetization change associated with magnetic resonance absorption. Magnetic resonance force microscopy (MRFM) [1] is known as a famous example of such applications, and can be applied to electron spin resonance (ESR) [2] and nuclear magnetic resonance (NMR) [3]. In particular, single electron spin sensitivity was achieved by Rugar *et al.* [4] using ultrasensitive cantilevers with a small magnetic tip.

Though the operating frequency of mechanically detected ESR typically ranges in the microwave region, its extension in higher frequency region has remarkable advantages such as high spectral resolution and ESR detection across the large zero-field splitting. So far, our group has developed mechanically detected high-frequency ESR techniques using a microcantilever [5, 6], and for example, reported multi-frequency ESR detection in the frequency region beyond 1 THz[7]. In these studies, commercial piezoresistive cantilevers [8] were used to measure ESR-induced magnetic torque of a single crystal of the magnetically anisotropic Co-Tutton salt.

Piezoresistive detection is one of most typical techniques to measure cantilever displacement. Compared to other techniques such as optical detection of motion, piezoresistive cantilevers are a self-sensing device and additional components are not needed. This remarkable features make their experimental setup easy and compact, though a care has to be taken for low-temperature use due to the Joule heating.

On the other hand, drawbacks of the piezoresistive detection are that commercially available piezoresistive cantilevers are limited, and more seriously their production often becomes discontinued. In fact, PRC400 and PRC120 supplied by Hitachi Hightechnologies (originally from Seiko Instruments) were most widely used piezoresistive cantilevers, but its production stopped in 2014. Another drawback is a relatively large stiffness of the commercial piezoresistive cantilevers, which thus limited the detection sensitivity. For example, PRC400 and PRC120 have a spring constant of 2-4 and 30-40 N/m, respectively, which is 10-100 times larger than those of contact-mode soft cantilevers. For this reason, softer cantilevers are strongly required to improve the sensitivity of piezoresistive detection of mechanically detected ESR. For this purpose, in-house microfabrication of such cantilevers will be a solution for con-

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