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Superconducting Proximity Effect on Piezoresistance in a Superconductor-Semiconductor Junction

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1. Introduction

Micro- and nanoelectromechanical cantilevers using semiconductor piezoresistivity are receiving increasing attention as sensitive force and displacement sensors [1-3]. The sensitivity can be improved by utilizing nonlinear device conductivity, which reads to large piezoresistance [2]. Therefore, if piezoresistive cantilevers include the structures that provide excellent nonlinear conductivity, ultrasensitive detection of small forces and displacements could become possible. Targeting the development of highly sensitive mechanical sensors, we have fabricated a novel micromechanical cantilever that integrates a superconductor-semiconductor-superconductor (S-Sm-S) junction. Although it is known that S-Sm-S junctions provide excellent nonlinear conductivity due to the superconducting proximity effect [4], the proximity effect on the piezoresistance has not been studied yet. In this study, we investigated the superconducting proximity effect on piezoresistance and obtained a strong enhancement in the piezoresistance using the normal-super phase transition.

2. Fabrication

The targeted cantilever was fabricated from InAs/AlGaSb heterostructures and a submicron-size niobium gap was patterned to form a Nb-InAs-Nb junction, at which deflection of the cantilever can be detected as resistance change, i.e., piezoresistance (Fig. 1). Figure 2(a) shows a scanning electron microscope (SEM) image of the fabricated cantilever. The length and width of the cantilever are 200 and 60 μm, respectively. The integrated InAs channel has a length of 0.3 μm and a width of 10 μm, being confirmed by the SEM image of the Nb-InAs-Nb junction [Fig. 2(b)].

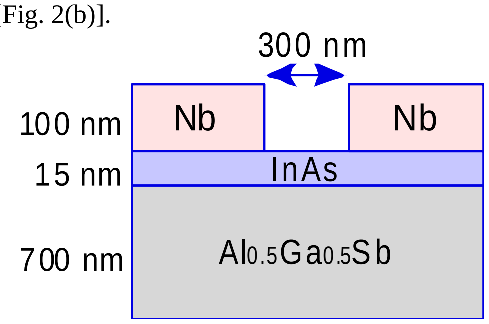

Fig. 1. Schematic illustration of the cross-sectional view of the S-Sm-S junction.

3. Results and Discussion

The resulting piezoresistance at ~2 K showed strong dependence on the bias current (I_{bias}) applied to the S-Sm-S junction (Fig. 3). Compared to the relatively small piezoresistance at $I_{bias} > I_c$ (where $I_c \sim 2$ μA is the superconducting critical current in this S-Sm-S junction), the piezoresistance was enhanced by two orders of magnitude around I_c, where the normal-super phase transition occurs in the InAs channel.

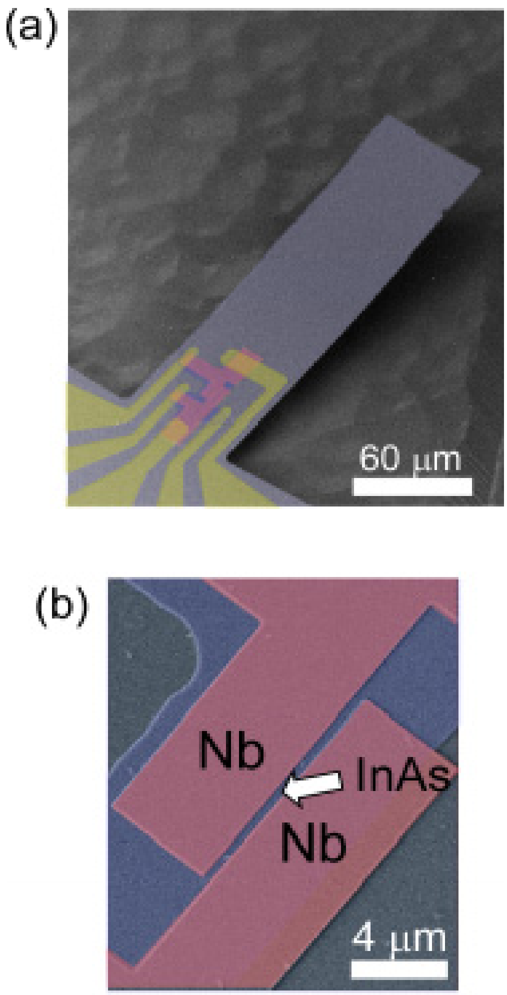

Fig. 2. SEM image of the fabricated cantilever (a) and the integrated Nb-InAs-Nb junction (b).

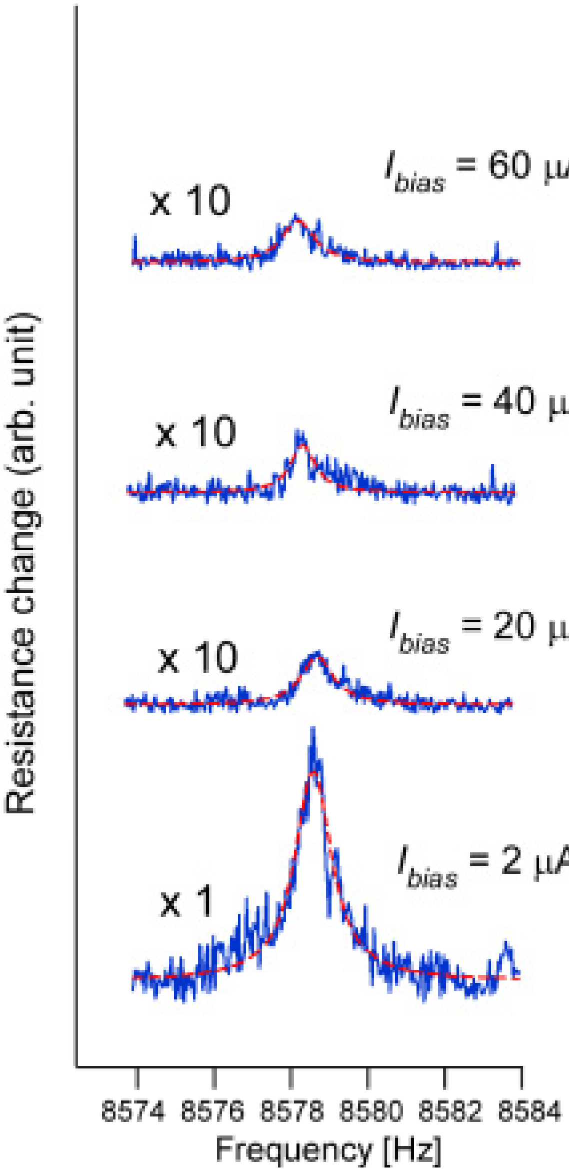

Fig. 3. The mechanical resonance characteristics of the fabricated cantilever at 2.2 K with the bias current (I_{bias}) of 60, 40, 20, 2, or 1 μA. The measured resistance change is shown as a function of driving frequency. We can find a strongly enhanced resistance change at the bias current of I_{bias} ~ 2 μA.

The enhanced piezoresistance would be caused by the modulation of the superconducting critical current. The mechanism is considered to be as follows: A key transport parameter for the diffusive semiconductor channel is the diffusion constant given by $D = \pi\hbar^2 N\mu / me$, where N is the carrier concentration, μ the mobility, and m the effective mass. If strain is induced at the S-Sm-S junction, N, μ, and m in the Sm channel are influenced and D is modified. The modified D changes the superconducting coherence length (ξ_T) because ξ_T is given using D by $\xi_T = \sqrt{\hbar D / 2\pi k_B T}$. Since I_c is influenced by ξ_T as $I_c \propto \exp(-1/\xi_T)$[5], the supercurrent is modulated by induced strain and strongly enhanced piezoresistance is obtained around I_c, where an excellent nonlinearity appears in device conductance.

3. Conclusions

We investigated the superconducting proximity effect on piezoresistance and obtained a strong enhancement in the piezoresistance using the normal-super phase transition. The results indicate that highly sensitive displacement and force sensors can be realized using a S-Sm-S junction.

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