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Experimental demonstration of a Josephson junction under spin current injection

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Abstract

A laterally configured Nb/Cu/Nb Josephson junction with two ferromagnetic Ni-Fe wires has been developed. We demonstrated that both the supercurrent and spin current propagate through the Cu channel. This indicates that Cooper pairs and spin accumulation coexist in the Cu channel. This unique situation provides an ideal platform for investigating the interaction between the cooper pair and electron spin.

1. Introduction

A spin-triplet superconductivity is an exciting subject because the triplet Cooper pair carries the spin current together with the charge current under the dissipationless condition. Therefore, utilizing the spin-triplet supercurrent provides may open a new avenue for developing ultra-low-consumption spintronic devices. However, since the triplet Cooper pair can be stabilized only in special superconducting materials such as Sr_2RuO_4 and UPt_3[1], it was believed to be difficult to use the triplet state in the practical application. Recent theoretical studies indicate that the triplet Cooper pair can be realized also in ferromagnet/superconductor hybrid structures by optimizing the exchange interaction between the Cooper pair and electron spin, where the singlet Cooper pair can be transformed into the triplet Cooper pair[2]. Recently, we have reported the spin transport property in a normal metal Cu/superconducting Nb bilayer system.[3] Although the results imply that the Cooper pairs and spin-polarized electrons coexist in a normal metal Cu layer, there was no clear evidence about the existence of the Cooper pairs in the Cu layer. To obtain more direct evidence, in the present study, we investigate spin and Cooper pair transport properties in a Josephson junction with ferromagnetic electrodes.

2. Experimental

Fig. 1 shows a SEM image of the fabricated device, consisting of ferromagnetic metal Ni-Fe, nonmagnetic normal metal Cu, and superconducting Nb wires. First we fabricated two Ni-Fe wires, 20 nm in thickness, on a SiO_2/Si substrate. Then, Nb/Cu bilayer wire, which makes a bridge between two Ni-Fe wires, was also fabricated. Here, the thicknesses for Cu and Nb are 100 nm and 30 nm, respectively. Since Nb and Cu were continuously grown without breaking the vacuum, the Nb/Cu interface has an ideal condition. Finally, the Nb layer in between two Ni-Fe wires was removed by the Ar-ion milling, resulting in the Nb/Cu/Nb Josephson junction.

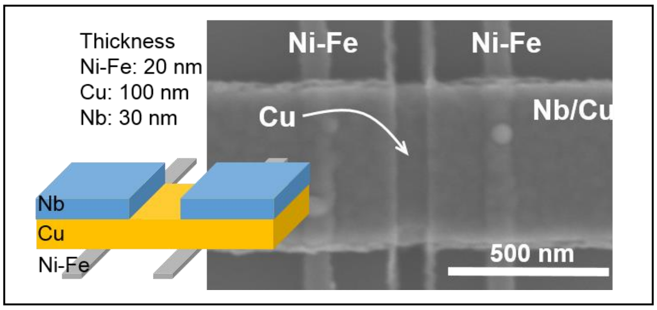

Fig. 1 SEM image and schematic structure of the fabricated device.

3. Results and Discussions

Fig. 2 shows the temperature dependence of the resistance of the Nb/Cu/Nb Josephson junction together with that for the Nb/Cu bilayer wire. The resistance of the Josephson junction becomes zero below 4.6 K, indicating the Cooper pair propagation through the Cu channel. Although the transition temperature is lower than that for the bilayer wire, the temperature difference is not so large, assuring the ideal Nb/Cu interfaces.

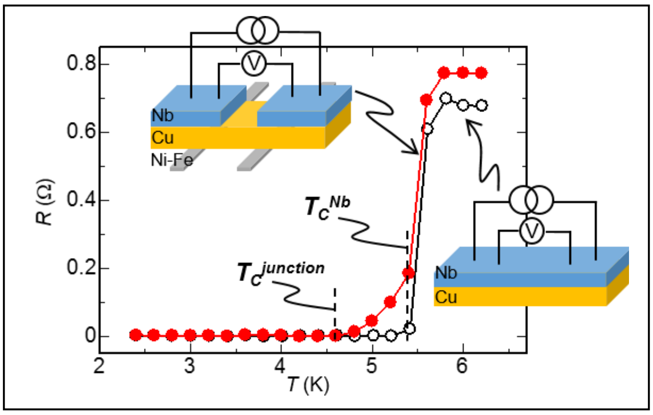

Fig. 2 Temperature dependence of the resistance

We then evaluated the spin transport property in the Josephson junction by using two Ni-Fe wires. First, we investigated the electrical resistance of the Josephson junction under the spin injection. Here, the spin polarized current was created in the Josephson junction by using two Ni-Fe wires as the current probes and the voltage drop was detected by two Nb pads as schematically shown in the inset of Fig. 3(a). Fig. 3(a) shows the bias current dependence of the resistance measured at 2.2 K. The clear zero resistance state has been confirmed below 100 μA under the spin injection, indicating that the injection charge current is converted into the supercurrent because of the proximity effect of the Nb.

The spin transport property of the Josephson junction has been measured by non-local spin valve signal with the probe configuration shown in the inset of Fig. 3(b). Here, the excitation current is 60 μA, which is smaller than the critical current of the Josephson junction. As can be seen in Fig. 3(b), a clear non-local spin valve signal was obtained even in the superconducting state, indicating the spin current propagates through the proximity-induce superconducting Cu channel. These results are the clear evidence that the Cooper pairs and the spin accumulation exist simultaneously in the Cu channel.

4. Conclusions

We have developed the fabrication method for obtaining the high performance Josephson junction. By preparing two ferromagnetic wires in contact with the Cu layer, we investigated the transport properties for the supercurrent and spin current. A zero resistance state under the spin injection and the clear spin valve signal strongly supports our expectation that the Cooper pairs and the spin accumulation coexists in the Cu channel.[3] This unique situation is ideal platform for investigating the interaction between the Cooper pair and the electron spin.

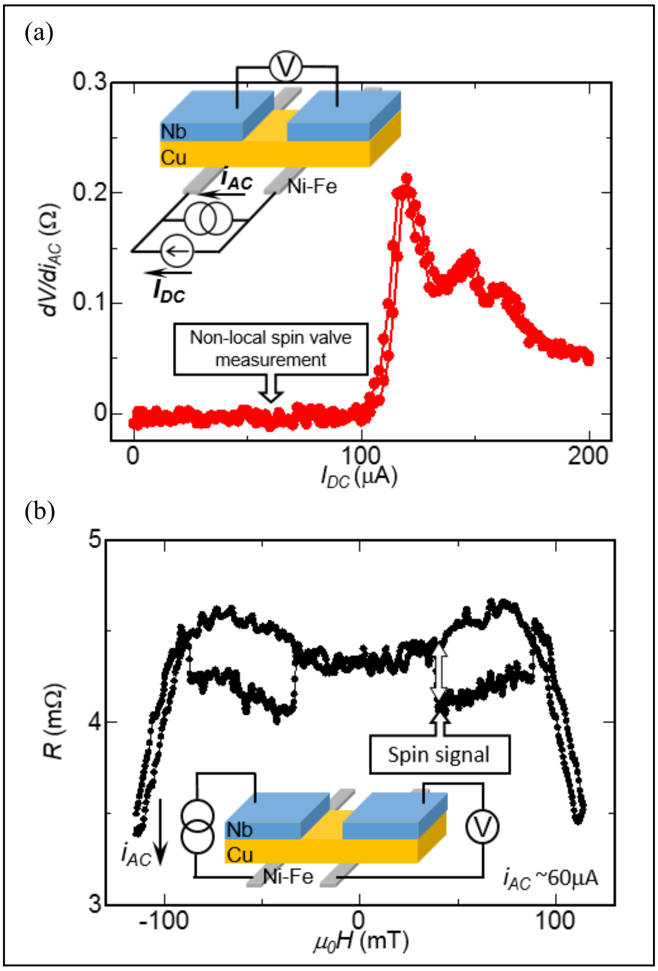

Fig. 3 (a) Bias current I_{DC} dependence of the differential resistance of the junction and (b) the non-local spin valve measurement. The measurements are performed at 2.2 K.

References

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