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Size Dependence of Peltier Cooling Effect in Heusler Compounds Co_2YSi (Y = Mn, Fe) / NM (NM = Au, Cu) Current Perpendicular to Plane Nano-pillars

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1. Introduction

Peltier cooling effect (PCE) that occurs while passing current at the interface between two different materials, could be one of the promising methods to cool down small electrical devices from inside. The bottom shift in a parabolic baseline of resistance-current (R-I) curves in current perpendicular to plane (CPP) giant magnetoresistance (GMR) elements is often observed in current induced magnetization reversal experiments. Fukushima *et al*. [1, 2] reported that the shift in the R-I curve in Co/Au CPP structures originates from the PCE, moreover, the Peltier cooling coefficient, Π evaluated from the R-I curves ($\Pi = R_0 I_P$, where R_0 and I_P are the zero current resistance, and the compensation current for heating and cooling, respectively) was few times higher than that of bulk. Recently, Sugihara *et al*. also reported a giant PCE in a submicron-sized Cu-Ni/Au CPP junction with nanometer scale phase separation [3]. However, the knowledge of PCE in CPP nano-pillar structures is still limited, and more systematic studies using different kinds of materials are requisite. Yoshida *et al*.[4] proposed the possibility of high thermoelectric cooling when electrons flow from nano-superstructure of half-metallic ferromagnet to paramagnetic metals by adiabatic spin-entropy expansion assuming the constant heat capacity of the CPP elements in addition to conventional Peltier effect. Half-metallic Heusler compounds especially, Co_2MnSi (CMS) is a potential candidate in spintronic devices because of its high Curie temperature (985 K) and large half-metallic band gap in minority spin channel (~ 0.4 eV at room temperature). The aim of this study is to investigate the PCE in the highly spin polarized CMS based CMS/Au (/Cu) nano-pillar junctions and to compare with other non-halfmetallic Heusler compounds such as Co_2FeSi(CFS)/Au structures.

2. Results

We have investigated PCE in CMS(40 nm)/Au(10 nm), CMS(40 nm)/Cu(10 nm) and CFS(40 nm)/Au(10 nm) cylindrical CPP nano pillar structures with designed pillar diameters D = 40 nm to 400 nm. The schematic diagrams of the top and side views of nano-pillar device structures are shown in Fig. 1(a) and (b). Figure 2 (a) shows the Peltier cooling coefficient Π (= $R_0 I_P$) evaluated from the R-I curves as a function of pillar diameter, D. A clear size dependence of Π has been observed in all three cases, which suggests qualitatively similar behavior irrespective of Heusler compounds CMS (or CFS) and non-magnetic Au (or Cu) combinations. Moreover, Π increases up to 15 to 30 times than that of bulk $\Pi_{Au(or\ Cu)/CMS(or\ CFS)}$ (= $(S_{Au(or\ Cu)} - S_{CMS(or\ CFS)})T$ ~ 6 mV, S represent the Seebeck coefficient ($S_{Au(Cu)}$ ~ 1.6 μV/K, and $S_{CMS(CFS)}$ ~ -20 μV/K at T = 295 K)) for D <120 nm. The values of Π for pillar diameters D > 140 nm in general is close to its bulk value. Typical R-I curves for D = 40 nm and D = 400 nm are shown in Figs. 2(a) and (b), respectively.

3. Summary:

The enhancement of Peltier coefficient has been observed in both types of Heusler compounds CMS/Au and CFS/Au interfaces irrespective of degree of spin polarization. In addition, similar behavior has also been observed in CMS/Cu structure. However, the present results could not be explained by the model of adiabatic spin entropy expansion [4] since the direction of current for cooling is opposite to that predicted by the model. Therefore, the mechanism of size dependence of large PCE is not clearly understood so far; moreover, systematic studies using other types of material are also underway to clarify the origin of such large Peltier cooling.

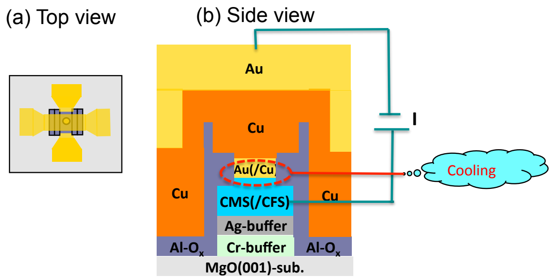

Fig. 1: Schematic diagrams of (a) top view and (b) side view of the device structures.

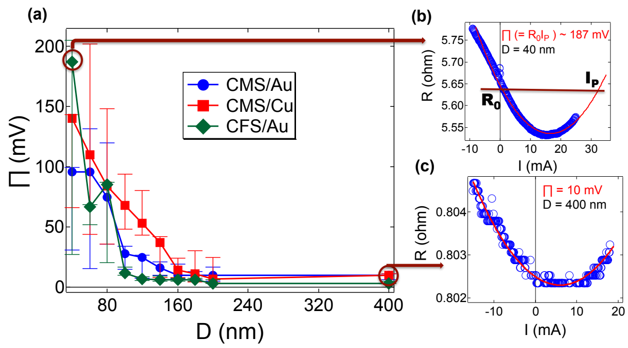

Fig. 2: (a) Peltier cooling coefficient Π as a function of pillar diameter D in CMS/Au, CMS/Cu and CFS/Au CPP nano-pillar structures, (b) R-I curves for D = 40 nm, and (c) D = 400 nm, respectively.

Acknowledgements

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