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Description	

Channel Width Dependence of Spin Polarized Transports in NiFe/InGaAs Hybrid Two-Terminal Structures

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Abstract

We investigated spin polarized transports in NiFe/InGaAs hybrid two-terminal structures at 1.5 K as well as their channel width dependence. The two-terminal structures were fabricated in order to neglect the local Hall effect (LHE) by fringe fields of NiFe contacts. First, we measured magneto-resistance (MR) characteristics of the samples under vertical magnetic fields, and obtained clear oscillations indicating the ohmic formation at NiFe/InGaAs interfaces. Next, we measured spin valve (SV) properties under parallel magnetic fields, and successfully observed clear SV peaks without LHE hysterisis loops. Furthermore, we also confirmed unique behavior of SV peaks depending on the channel width. Such dependence also indicates spin injection/detection through NiFe/InGaAs interfaces.

Keywords: Spin polarized transports, NiFe/InGaAs hybrid, Local Hall effect (LHE), Magneto-resistance (MR), Spin valve (SV)

1. Introduction

Recently, semiconductor-based spin devices have been paid much attention because these can control the number of electrons as well as electron spin nature. In particular, spin field effect transistors (spin-FETs) proposed by Datta and Das [1] are one of the most important device, because their operation is based on the combination of spin filter by ferromagnetic (FM) electrodes and spin precession by spin-orbit (SO) interaction of channel electrons. Furthermore, such spin-FETs are much expected to be a candidate for the base device of quantum computing.

In order to realize such spin-FETs, we have studied spin transports in metamorphic In(Ga)As/InAlAs heterostructures with high indium content, because these show large SO interaction due to their narrower band-gap. We successfully reported control of spin precession by a top-gate [2] and side-gates [3], and spin injection from an FM electrode [4, 5]. However, in the case of spin injection experiments, it was difficult to obtain clear spin valve (SV) signals in the conventional configuration indicating spin injection/detection probably because of the local Hall effect (LHE) by fringe fields of FMs.

In this paper, we report on spin polarized transports in simple two-terminal structures in order to neglect LHE via fringe fields. As a result, we demonstrate clear magneto-resistance (MR) oscillations as well as SV signals without LHE hysterisis loops. Furthermore, we also show unique behavior of SV peaks depending on the channel width.

2. Experimental procedure

Our heterostructures having large SO interaction were a metamorphic

InGaAs/InAlAs modulation doped heterostructure with indium content of 75% grown by solid-source molecular beam epitaxy. Figure 1 shows top view and schematic cross-sectional view of a NiFe/InGaAs hybrid two-terminal structure. We fabricated three kind of samples with different channel width, W = 1.6 μm, 2.5 μm and 6.2 μm. The channel length, L, was fixed to 2.2 μm. We used 30-keV electron-beam lithography and wet etching with H_2SO_4-base solution for the fabrication of 400-nm-depth mesa. 50-nm-thick NiFe contacts were fabricated on side walls of the mesa structures by radio-frequency sputtering process. We note that Ar-ion etching during 2 minutes in the same chamber was carried out before NiFe deposition in order to remove native oxides on contact area. Spin polarized transport measurements were carried out utilizing AC lock-in technique in a conventional liquid He cryostat with a super conducting magnet. Typical measurement temperature was 1.5 K.

3. Results and Discussions

3.1. Magneto-resistance and contact resistivity

Figure 2 shows two-terminal MR characteristics of the samples under vertical magnetic fields. We successfully observed clear MR oscillations i.e. Shubnikov de-Haas oscillations which indicate the existence of two-dimensional electron gas (2DEG) channel and well ohmic contacts at NiFe/InGaAs interfaces. From a Hall-bar sample without FM contacts i.e. with NM contacts, electron concentration and mobility were estimated from $N_S = 5.1\times10^{11}$ cm^{-2} and $\mu = 5.4\times10^4$ cm^2/Vs, respectively. Furthermore, SO interaction parameter could be estimated to be $\alpha = 3.8\times10^{-12}$ eVm from fast Fourier transform analysis of MR oscillations.

Figure 3 shows estimation of various resistance and contact resistivity from MR characteristics. For the estimation, we assume that the resistance of InGaAs 2DEG, R_S, is simply calculated from N_S, μ , L and W as a following equation.

$$R_S = \frac{L}{W}(eN_S\mu)^{-1} \qquad (1)$$

Additionally, the measured two-terminal resistance, R_{2T}, is also assumed as a following equation.

$$R_{2T} = R_S + 2R_C \qquad (2)$$

Here, R_C is the contact resistance of a single NiFe/InGaAs interface, and the contact resistivity should be defined by a product of R_C and W. With the uniform interfaces, $R_C \times W$ is expected to be independent of W. However, estimated $R_C \times W$ from the experimental results was slightly reduced as the channel became narrower. Additionally, we found that samples having narrow channel tended to be difficult to carry out transport measurements due to high R_{2T}. The results suggest fluctuation at NiFe/InGaAs interfaces. Thus the interfaces had high and low conductive regions. Therefore, measurable narrow channel samples had only high conductive region, and resulted in fine $R_C \times W$. Wide channel samples had both high and low conductive regions, and resulted in higher $R_C \times W$ and much measurable probability compared with narrow channel samples.

3.2. Spin valve properties and their channel width dependence

Figure 4 shows SV properties of samples at 1.5 K. Symmetrical SV signals were clearly observed without hysterisis loops. The results strongly suggest that the present design indeed reduces the LHE. Additionally, we note that the results were obtained in longer channels with L = 2.2 μm compared to the mean free path, l_e = 0.6 μm. The fact indicates that the spin relaxation should not be induced by the elastic scattering.

Furthermore, we found some unique features of spin valve peaks. Figure 5a shows the plots of SV peak amplitude. We confirmed slight enhancement of peak amplitude by squeezing channel width. We think that the result corresponds to coherent spin transport in the narrow channel due to the limit of transport direction which suppresses the spin precession motion of electrons in the channel [5].

Figure 5b shows peak positions and full-width half-maximum (FWHM). From the plots, as the channel width became narrower, the peak shape became sharpened and the positions were shifted close to zero field. We think such peak behaviors originate from the coercive force of FM contacts. Thus, it unfortunately depended on the aspect ratio of effective contact regions corresponding to mesa side-walls and/or excess FM parts on mesa-top. However, the results also suggest successful spin transport in the present samples due to these channel width dependence.

4. Summary

We investigated spin polarized transports of NiFe/InGaAs hybrid two-terminal structures. We measured MR and SV characteristics of the samples at 1.5 K, and obtained clear MR oscillations and SV peaks without LHE hysterisis loops. Furthermore, we also confirmed unique behavior of SV peaks depending on the channel width. Such dependence indicates spin injection/detection through NiFe/InGaAs interfaces.

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Figure captions

Fig. 1. Top view and schematic cross-sectional view of a NiFe/InGaAs hybrid two-terminal structure.

Fig. 2. First derivative of magneto-resistance of samples at 1.5 K.

Fig. 3. Plots of various resistances and contact resistivity as a function of W.

Fig. 4. Spin-valve properties of the samples at 1.5 K. Black arrows indicate spin valve peaks.

Fig. 5. Details of spin valve peaks. (a) Amplitude of spin valve peaks. (b) Peak position and full-width half-maximum of peaks.

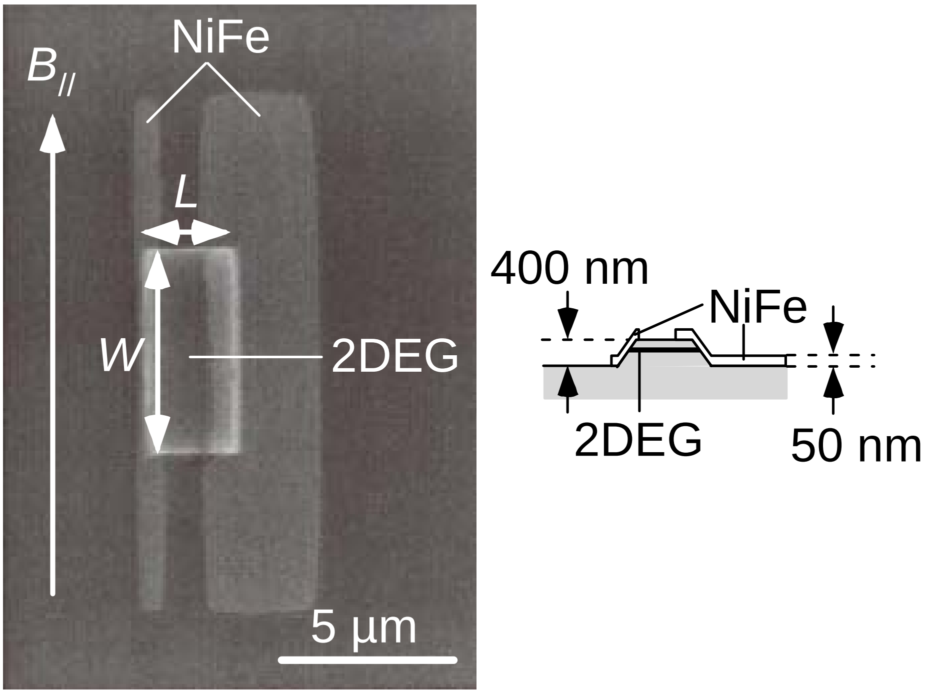

Figure 1. M. Akabori *et al*.

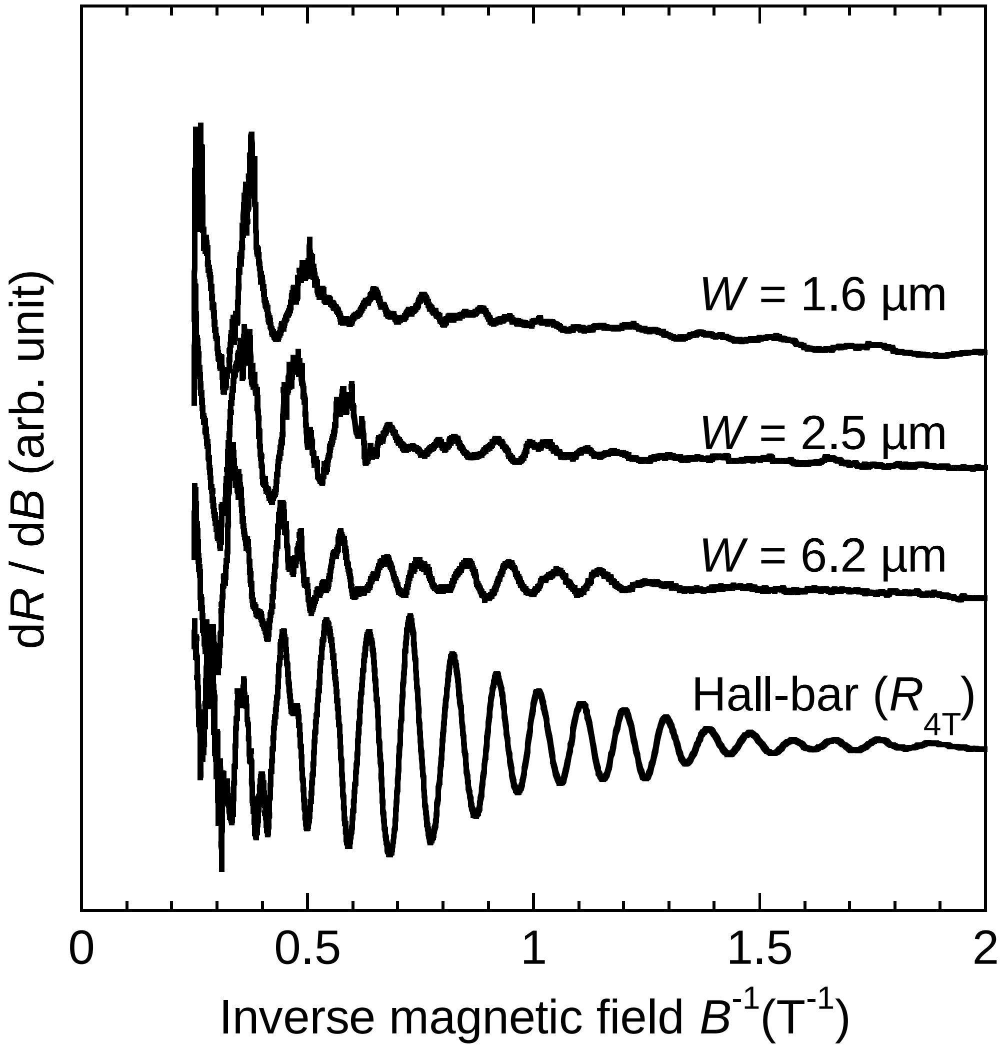

Figure 2. M. Akabori *et al*.

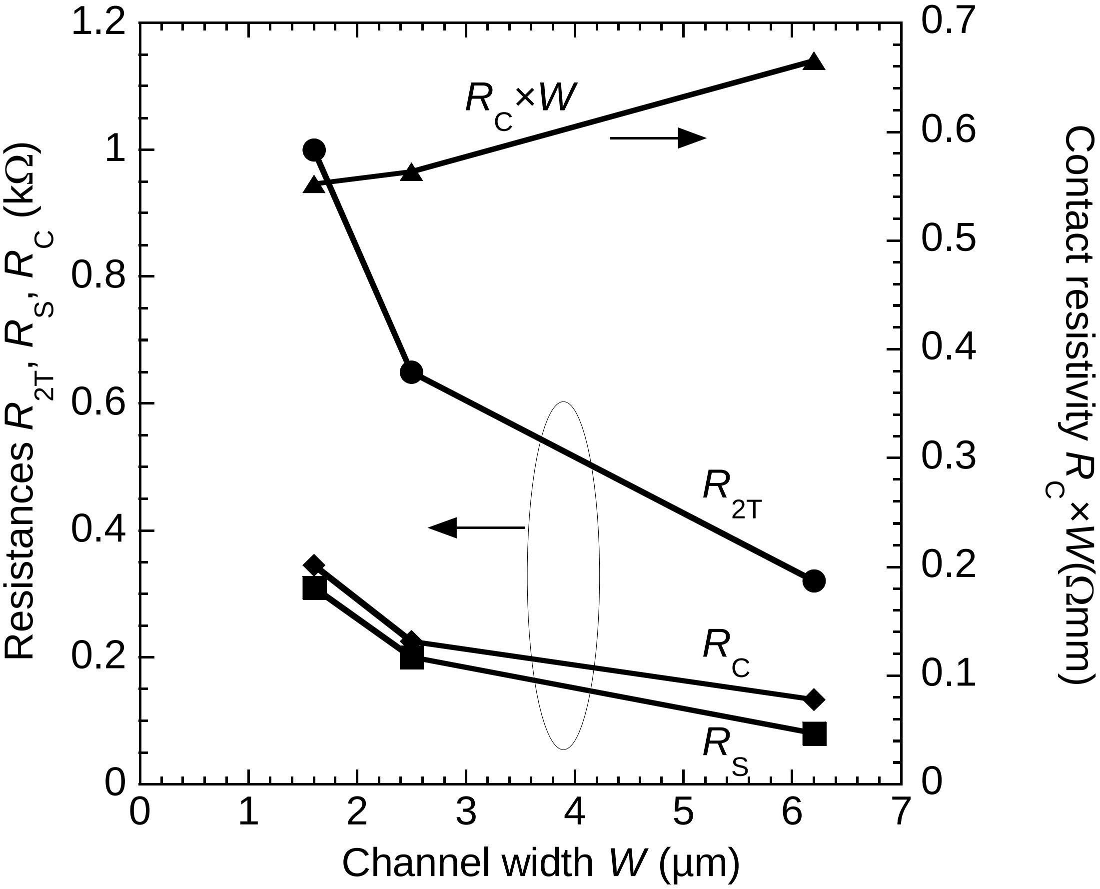

Figure 3. M. Akabori *et al*.

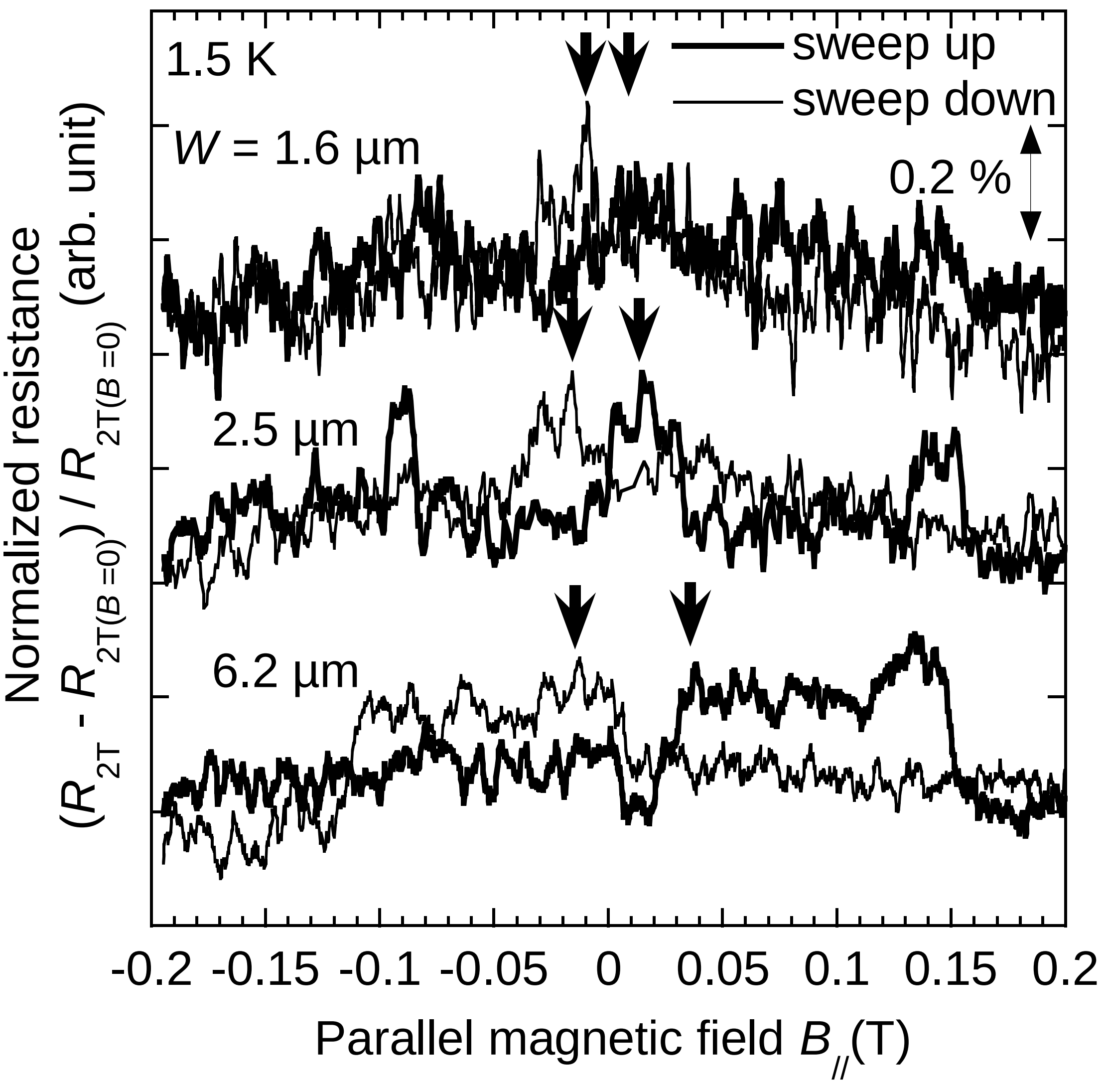

Figure 4. M. Akabori *et al*.

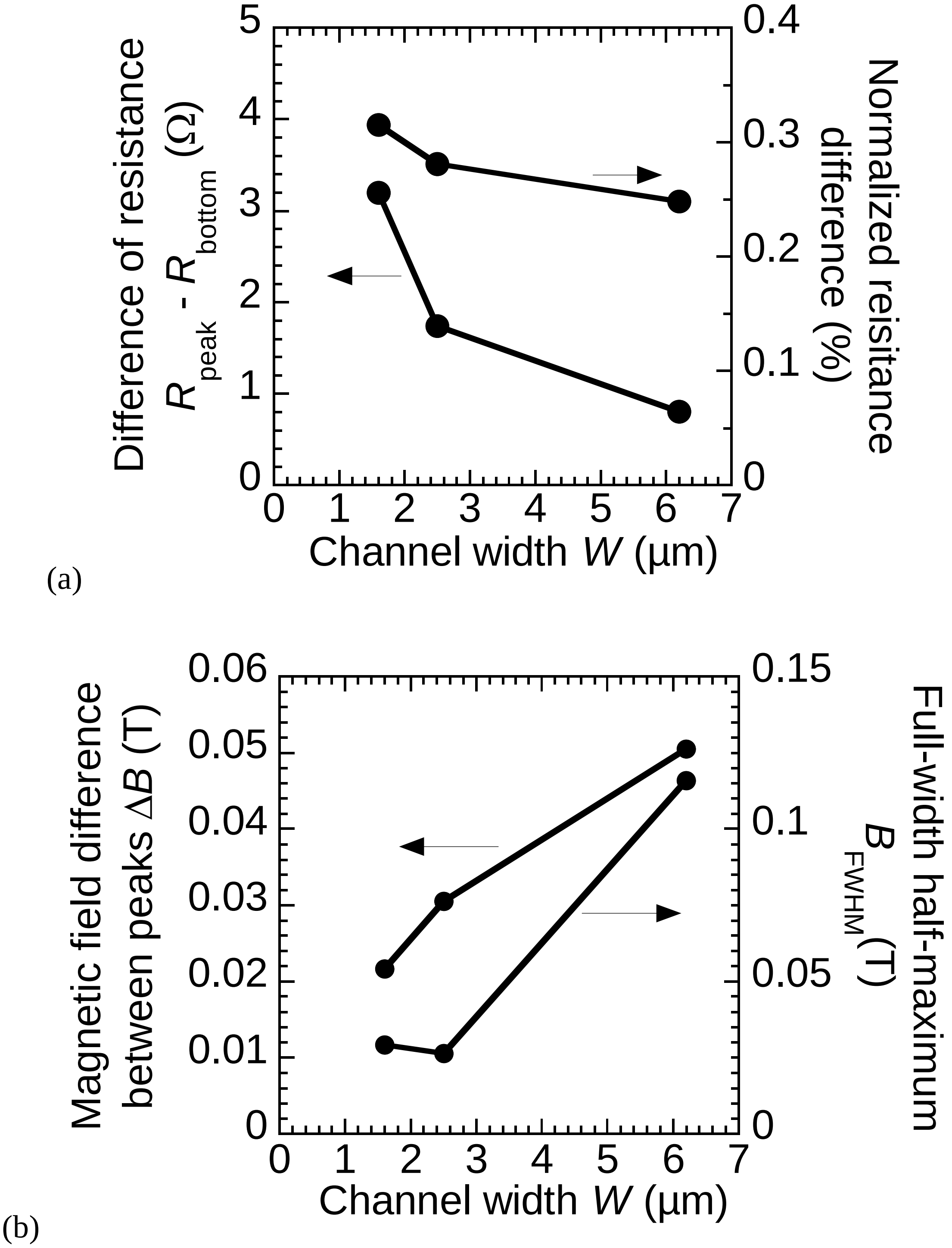

Figure 5. M. Akabori *et al*.