Observation of Direct Spin Injection from NiFe into an InAs Nanowire

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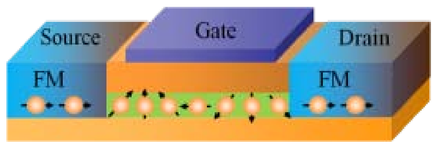
Introduction

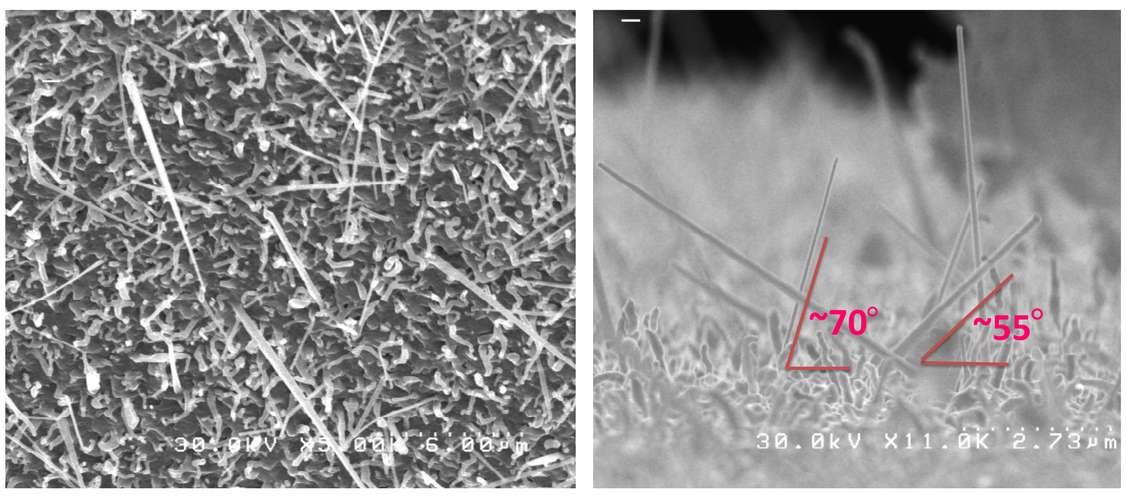
Datta-Das type spin FET structure [1] is expected to operate in a condition when Rashba and Dresselhaus effect are matched (PSH state).[2-4] It is also suggested that one dimensional Datta-Das spin FET is more effective in keeping long spin relaxation length.[3] InAs nanowire is a good candidate for the spin device channel material because Rashba coefficient α and Dresselhaus coefficient β of InAs are both large and comparable. To apply this quasi-1 dimension material, it is necessary to quantify the spin transport properties and control fabrication processes of InAs nanowires grown along [110] directions.

[1] S. Datta and B. Das, Appl. Phys. Lett. 56, 665 (1990).
[2] Munekazu Ohno and Kanji Yoh, Physica E 40, 1539-1541 (2008)
[3] J. Schliemann, Phys. Rev. Lett. 90,146801 (2003).
[4] M. Ohno and K. Yoh, Phys. Rev. B 77, 045323 (2008).
[5] Hongyi. Xu, et al., Nano Lett., 12 (11), pp 5744–5749 (2012); R.Perumal and K.Yoh, unpublished.
[6] Z. Cui, T. Ishikura, F. Jabeen, J.-C. Harmand, K. Yoh, J. Crystal Growth, in press.

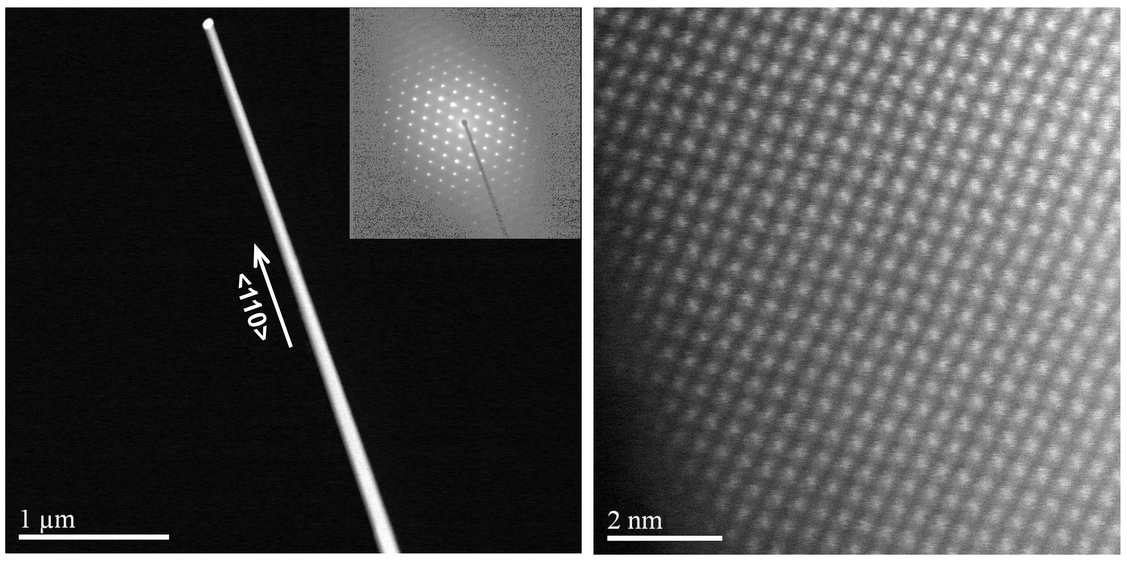


InAs Nanowire Growth

InAs nanowires were grown on GaAs{111}$_B$ substrate by Pd-assisted Vapor-Liquid-Solid growth mechanism using molecular beam epitaxy. [5] The impacts of the catalyst particle density, growth temperature and input V/III precursor ratio have been investigated to identify a better growth condition for getting high density InAs nanowires. We assert here that the grown nanowires are projected along <110> directions with respect to the substrates, having pure zinc-blende crystalline structure with free of stacking faults. (Diameter= 150nm, Length= 10µm)

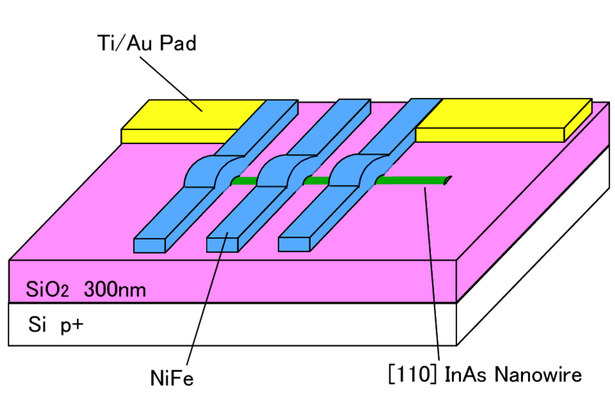


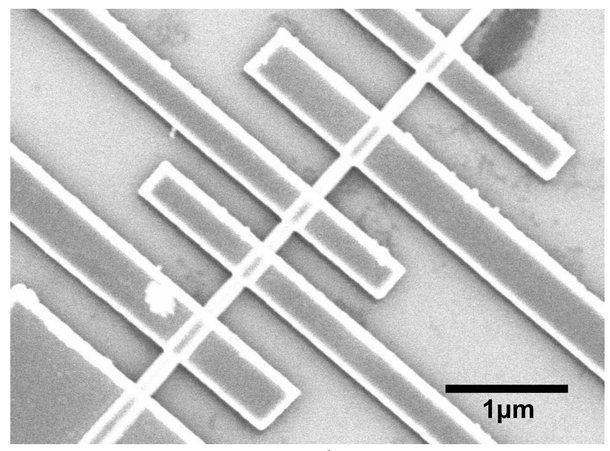
SEM image with corresponding diffraction pattern of the grown nanowire



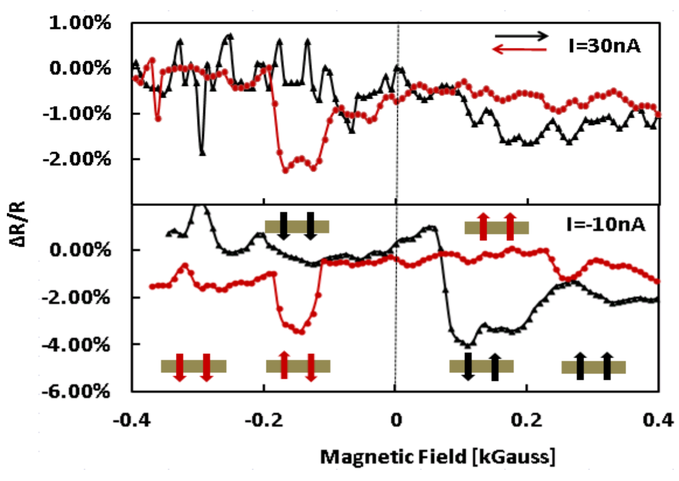
TEM image with corresponding diffraction pattern of the grown nanowire

Measurements





Schematic and SEM image of InAs nanowire spin injection device.
Ferromagnetic metal: NiFe

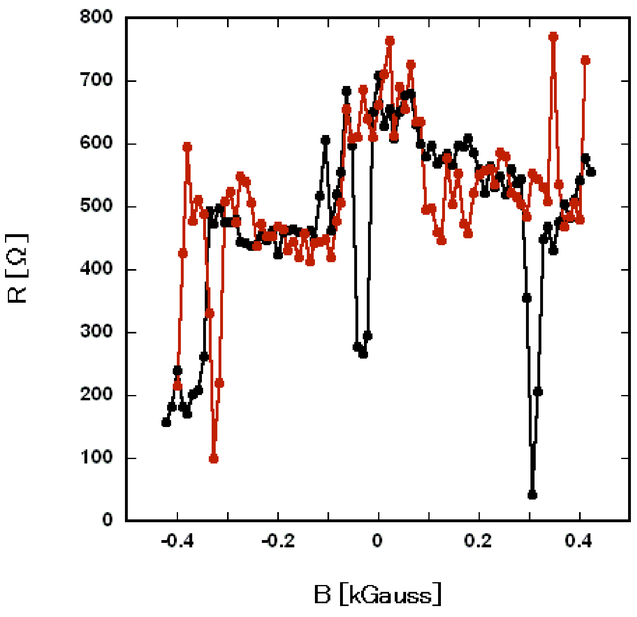


The relative magnetoresistance (MR) characteristics in two different bias currents at 20K of device pre-etched with $(NH_4)_2S_x$.

$$MR = \frac{\Delta R}{R_p} = \frac{\gamma^2}{1-\gamma^2} \frac{2}{2\cosh\left(\frac{L}{l_{sf}}\right) + \left(\frac{R_b}{R_{ch}} + \frac{R_{ch}}{R_b}\right)\sinh\left(\frac{L}{l_{sf}}\right)}$$

Channel length: L= 300nm
Contact resistance: R_b = 20kΩ
Channel resistance: R_{ch} = 5kΩ

Assuming the spin relaxation length l_{sf} to be 290nm in an InAs nanowire measured separately [6] and the maximum theoretical l_{sf} to be 10µm [2], the estimated spin injection efficiency ranged from 20% (l_{sf}=10µm) to 35% (l_{sf}=290nm).



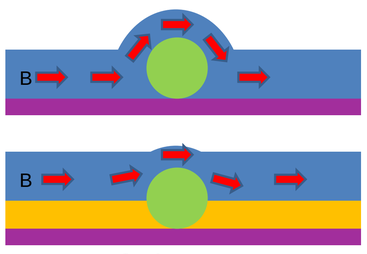
Non-local spin injection measurement at 1.5K of device pre-etched with Ar+ plasma.

The estimated spin polarization P ranged from 12% (l_{sf}=10µm) to 32% (l_{sf}=290nm).

$$\Delta R = \frac{R_{ch} l_{sf} P^2}{w} \exp\left(-\frac{L}{l_{sf}}\right)$$

Channel length: L= 400nm
Channel width: w= 150nm
Channel resistance: R_{ch} = 7kΩ

The distortions at the nanowire intersection might impact the magnetic switching field of NiFe electrodes. Appearance of excrescent peaks could be avoided by planarization process.



Schematic of planarization process.

Conclusions

We have grown [110] InAs nanowire and fabricated nanowire spin injection device with non-alloyed ferromagnetic contacts. The relative magnetoresistance (MR) and spin polarization characteristics suggests Pd-mediated-VLS-grown InAs nanowires to be a candidate channel material of practical spintronics devices.