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Synthesis and magnetic properties of diluted magnetic semiconductor (DMS) Ge nanowires

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1. Introduction

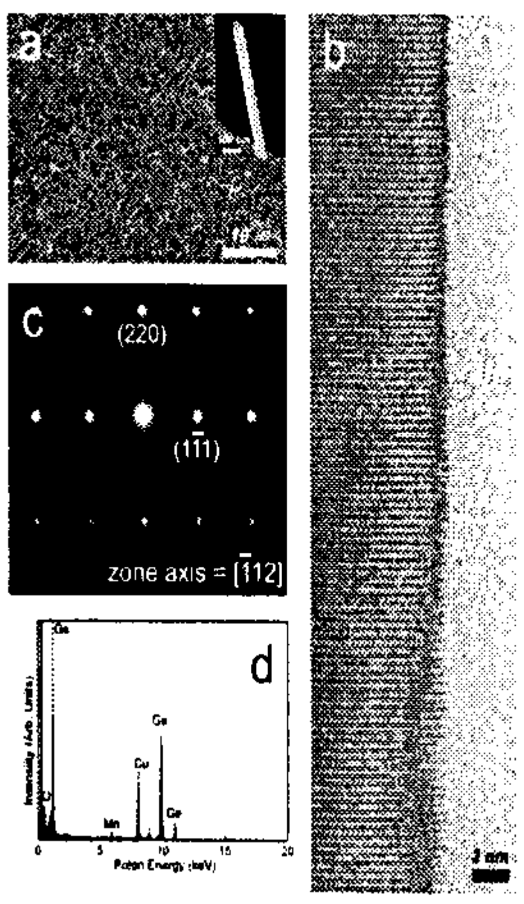
Diluted magnetic semiconductors (DMSs) combine the electronic transport properties of semiconductors and memory characteristics of magnetic materials, and have been extensively studied as candidates for spin-based electronic and optoelectronic devices.[1-3] Expecially, single crystalline one-dimensional semiconductor nanostructure (nanowire) has received an enormous amount of attention as building blocks to address the magnetism in DMSs because the significant controversy still exists over the possible magnetic impurity phase separation for many thin-film studies.[4-5] Among these, transition metal doped Ge (IV group semiconductor-based) system has been recently interested due to the compatibility of Ge to CMOS process and its high electrical properties.[6-7] Here, we report on the synthesis of single crystal Mn doped Ge nanowires and their magnetism.

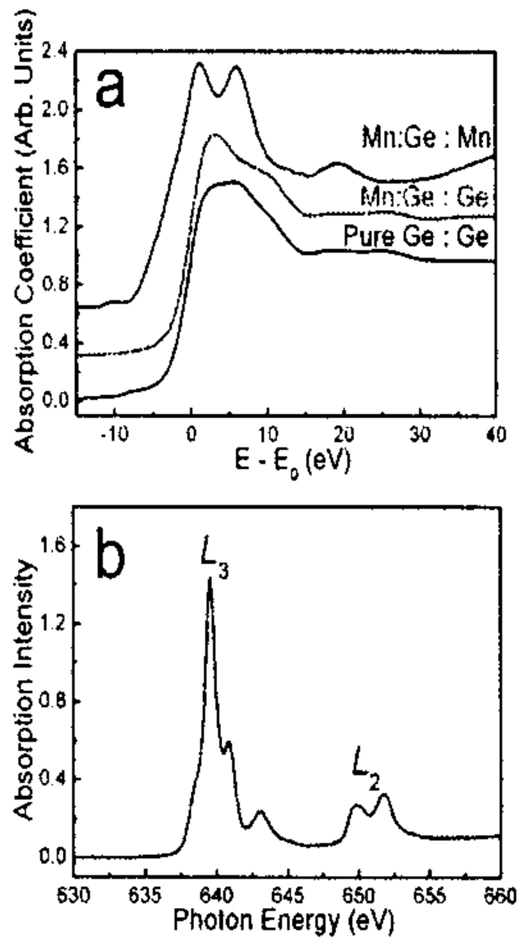
2. Experimental Methods

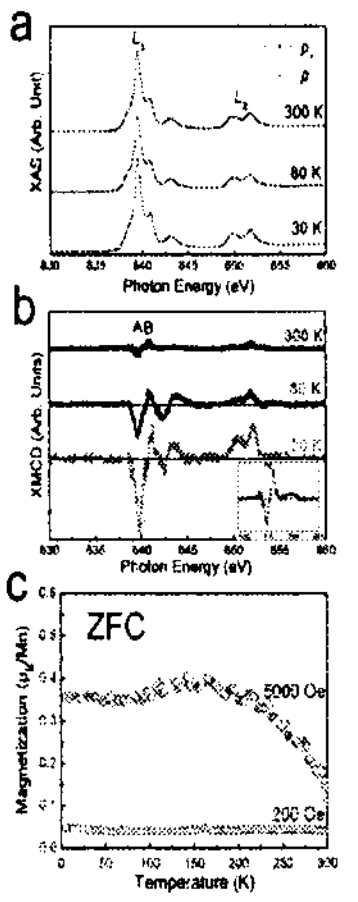
Single crystalline Mn:Ge nanaowires were synthesized using a Au catalyst deposited silicon substrates in a germanium tetrachloride ($GeCl_4$) based chemical vapor transport system. The substrates with a 2 nm layer of Au were inserted into the center of a quartz tube and $MnCl_2$ (purity 99.99%) powder as doping source was placed at a distance of 1 inch away the substrates. The temperature of the furnace was increased at a rate of $50^{\circ}Cmin^{-1}$ to $600^{\circ}C$ under a flow H_2 and Ar at a rate of 100 and 300 sccm, respectively. Simultaneously, $GeCl_4$ as Ge source was introduced into the tube using H_2 carrier gas that was bubbled through liquid source held at $15^{\circ}C$ at a flow rate of 3 sccm for 10 min and then cooled down to room temperature under H_2 and Ar atmosphere.

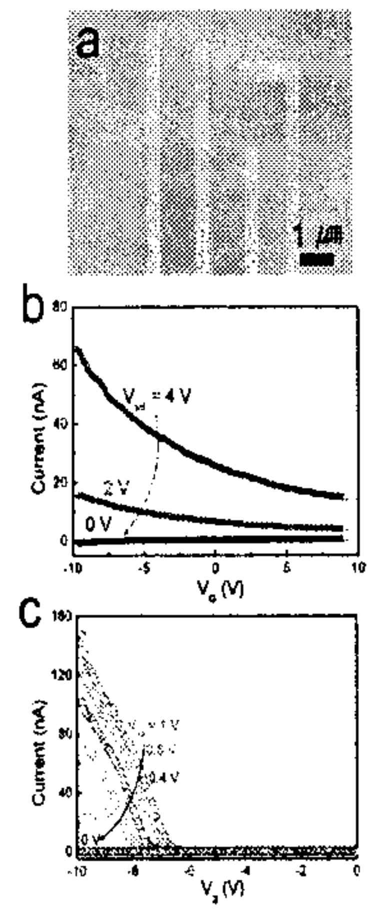
3. Results and Discussions

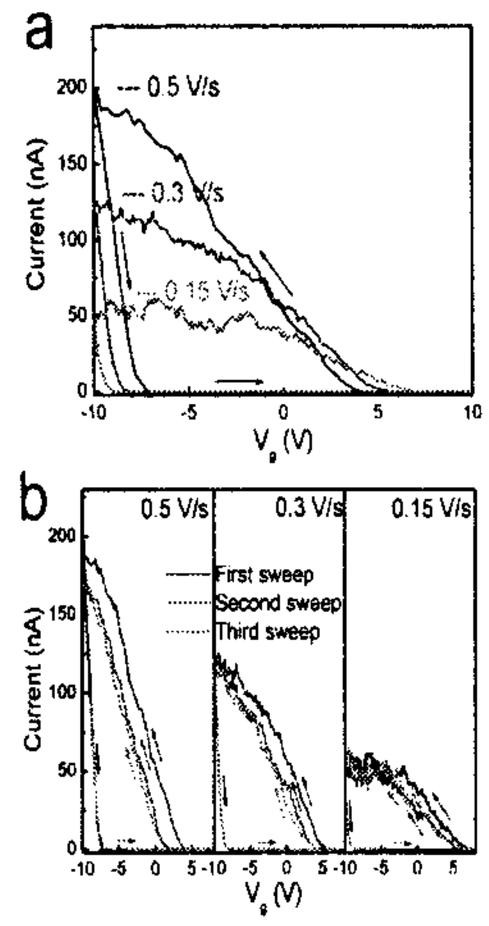
The typical diameter and length of the Mn:Ge nanowires are from 80 nm to 100 nm and tens of micrometers, respectively. The average concentration of Mn doped in these nanowires is c.a. 1.5 %. The electrical measurements exhibit that Mn:Ge nanowire field effect transistor (FET) electrically shows the p-type characteristic property. The x-ray absorption fine spectroscopy (XAFS) measurements for Mn and Ge K-shell reveal that Mn atoms are substitutionally present at Ge sites and no signatures of other sites of Mn were observed. Mn x-ray absorption spectra (XAS) and x-ray magnetic circular dichroism (XMCD) measurements in the Mn $L_{2,3}$ absorption edges indicated that Mn^{2+} and Mn^{3+} are ferromagnetically co-existent in the nanowires with Mn^{2+} as a major component, and the ferromagnetic coupling between Mn ions is driven by a carrier-induced mechanism that is simultaneously mediated by the hole in the Mn band and carrier. Our Mn:Ge nanowires suggest CMOS compatible-, room temperature ferromagnetic DMS.











4. Conclusions

In summary, we observed room temperature ferromagnetism in single crystalline Mn:Ge nanowires. Our characterization showed that the Mn ions are substitutionally doped and incorporated with 2+ and 3+ charge states with Mn^{2+} as a major component. It indicates that the ferromagnetic coupling between Mn ions is driven by a carrier-induced mechanism that is simultaneously mediated by the hole in the Mn band and carrier. Our results would helpful in understanding the carrier-mediated ferromagnetism in DMSs since the ferromagnetism was observed in *p*-type semiconductor. It would also helpful for developing CMOS compatible-, room temperature ferromagnetic DMSs.

5. References

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