Synthesis and Microstructural Study of Fe-doped Zn$_{1-x}$Cu$_x$O Diluted Magnetic Semiconductor Nanowires


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Diluted magnetic semiconductors (DMSs) have drawn much attention and interesting in recent years because of the possibility involving charge and spin degrees of freedom in a single substance [1]. However, as dimension closed to nanoscale, the quantum effect will also be even more apparent. One-dimensional (1-D) nanowire heterostructures are potentially functionalities feasible for nanoscale electronics and optoelectronics [2, 3]. Hence, synthesis of DMS nanowire heterostructure is of particular interest in nanoscale spintronics. Moreover, it is necessary to understand the correlation of magnetic properties and microstructure in DMSs with spatial resolution of near or even better than nanometer scale.

In this letter, we study a systematic work of synthesis, microstructure, and magnetic measurements on 1-D Fe-doped Zn$_{1-x}$Cu$_x$O nanowires. These are synthesized and proceeded by using thermal evaporation and ion implantation, in which the dose of the Fe ions implanted into the Zn$_{1-x}$Cu$_x$O nanowires are $3 \times 10^{16}$ cm$^{-2}$, and $5 \times 10^{16}$ cm$^{-2}$, respectively. Atomic scale structural characterization including high-resolution transition electron microscope (HRTEM), and nanobeam energy dispersive x-ray spectroscopy (EDX) map were done to study the behavior of Fe atoms. Figure 1(b) shows the HRTEM image of Fe-doped Zn$_{1-x}$Cu$_x$O nanowires with the [0001] growth direction of single crystal, which is the same as that of as-grown Zn$_{1-x}$Cu$_x$O nanowire (Fig. (a)), for the dose of $5 \times 10^{16}$ ions/cm$^2$. It also suggests that any nano-sized clusters or second phase are absence in the Fe-doped Zn$_{1-x}$Cu$_x$O nanowires. Figure 2 is the subsequently EDX elemental map analysis. It is apparent that Fe element is successfully doped into Zn$_{1-x}$Cu$_x$O nanowires of well-controlled size and exhibits gradually enhanced magnetic behavior with increasing Fe element from a superconducting quantum inference device magnetometer measurement. Furthermore, the characteristic iron L$_2$ and L$_3$ absorption edge was analyzed by using electron energy loss spectrum. Further calculations on the ratio of the integrated intensity counts, done on the L$_3$ and L$_2$ absorption edge of iron, correspond to valence state of +3 [4]. This suggests that Fe ions supplies an extra electron carrier and contributes the inherent magnetic properties based on the double-exchange mechanism.

Reference


The authors profusely thank the National Science Council of R. O. C. (NSC 92-2216-E-007-039) for the financial support of this work.
Fig. 1. The HRTEM image of (a) as-grown Zn$_{1-X}$Cu$_X$O nanowire and (b) Fe-doped Zn$_{1-X}$Cu$_X$O nanowires for the dose of $5 \times 10^{16}$ ions/cm$^2$.

Fig. 2. The EDX elemental map of Zn, O, Cu, and Fe for the Fe-doped Zn$_{1-X}$Cu$_X$O nanowires with the dose of $5 \times 10^{16}$ ions/cm$^2$.

Fig. 3. Electron energy loss spectrum analysis of the characteristic iron L$_2$ and L$_3$ absorption edge based on the double arctangent background subtraction function.