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Synthesis of VO_2 Nanowire and Observation of the Metal-Insulator Transition

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Abstract

We have fabricated crystalline nanowires of VO_2 using a new synthetic method. A nanowire synthesized at 650℃ shows the semiconducting behavior and a nanowire at 670℃ exhibits the first-order metal-insulator transition which is not the one-dimensional property. The temperature coefficient of resistance in the semiconducting nanowire is 7.06 %/K at 300 K, which is higher than that of commercial bolometer.

One dimensional (1-D) nanostructure materials exhibit unique physical properties that differ from their bulk properties. It is due to a characteristic of the 1-D structure such as nanotubes, nanorods, and nanowires [1-3]. It is well-known that an abrupt metal-insulator transition (MIT) and a hysteresis behavior do not occur in 1-D structure. These are an advantage for a device application. Therefore, synthetic efforts for 1-D materials have been continued by many researchers, although synthesis of 1-D structures is very difficult. The transition oxide material, VO_2, undergoes the structural phase transition (SPT) from the monoclinic to the rutile tetragonal structures near 340 K. It was revealed that the first-order MIT is controlled by hole doping of a low density and is not caused by the SPT; this demonstrated the Mott transition [4]. VO_2 has a lot of applications such as electro-optic switch, infrared bolometer, and the Mott first-order field effect transistor (FET), *etc*. New ideas for the first-order MIT transistor were disclosed by Kim and Kang [5] and Chudnovski et al. [6]. For the fabrication of nanometer-scale Mott FET devices, the synthesis of single-crystalline VO_2 nanowires was reported [7]. Metastable VO_2 nanowire arrays were synthesized via an ethylene glycol reduction approach [8].

In this paper, we reports synthesizing conditions of VO_2 nanowires fabricated by using a synthetic method. Their electrical characteristics are analyzed by measuring the temperature dependence of resistance and I-V characteristics. In particular, to our knowledge, we first observed first-order MITs in nanowires.VO_2 nanostructures with nanoblock and nanowire were successfully synthesized by controlling the oxygen partial pressure in the oxidation process of metallic vanadium. The metallic vanadium was grown on α-Al_2O_3 (01-10) substrate at 500 ℃ in an Ar ambient atmosphere of 50 mTorr using RF Sputter.

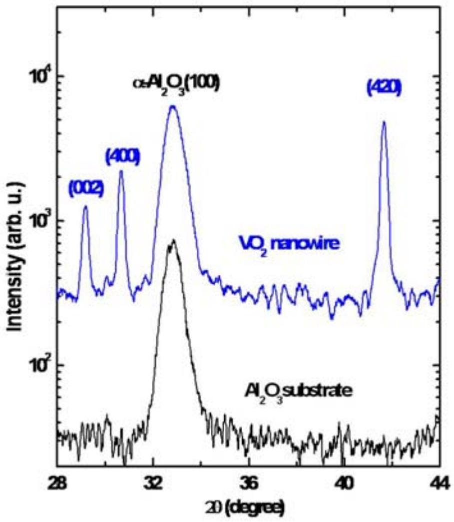

Fig. 1 The crystal structure of a VO_2 nanowire grown at 670 ℃ for 30 minutes. XRD pattern of the VO_2 nanowire compared to JCPDS.

Advantage of this new method is a shorter synthesis time than that of other nanowire fabrication methods such as thermal chemical vapor deposition [9] and the bulk crystal growth method [6]. The use of Al_2O_3 substrate different from SiO_2/Si derived more high quality nanowire on the basis of the fact that VO_2 film is well-grown on Al_2O_3. Annealing was performed at 630~670℃ in the O_2 ambient atmosphere of 50 mTorr for 30~60 minutes.

Figure 1 shows an X-ray diffraction (XRD) pattern of the crystal structure of a VO_2 nanowire grown at 670℃ for 30 minutes. Lattice constants from XRD peaks are calculated as a=12.03 Å, b=6.693 Å, c=6.42 Å, which is in agreement with the reported values of the monoclinic VO_2 for JCPDS (card No. 71-0042) [10]. (400) peak is the most intense peak of typical VO_2 thin film grown on α-Al_2O_3 substrate.

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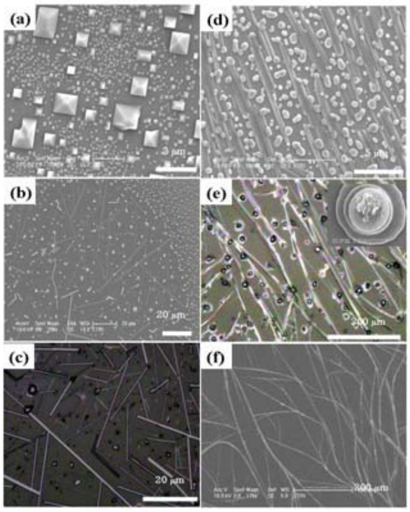

Fig. 2 SEM images of VO_2 nanostructures. The annealing temperatures and times are as follows: (a) 630 ℃, (b) 650 ℃, (c) 670 ℃ for 30 min, and (d) 40 min, (e) 50 min, (f) 60 min at 670 ℃.

Figure 2 (a)~(c) show high resolution scanning electron microscopy (SEM) images of nanostructures synthesized at several annealing temperatures. The nanostructures are the semblance nanoblocks (quadrangular pyramid) and nanowires. Nanoblocks with a size of 50~500 nm were synthesized at 630 ^{o}C. Nanoblocks and wires coexist at 650 ^{o}C. Only nanowires were grown at 670 ^{o}C. The nanowires in Fig. 2(c) are rectangular parallelepiped form with a length of 10~800 µm (z-axis), a width of 20~150 nm (y-axis) and a thickness of 100~500 nm (x-axis).
Annealing time for fabrication of good nanowires was also changed from 40 to 60 minutes with step of 10 minute, as shown in Fig. 2 (d)~(f). When annealing time was 40 min (Fig. 2(d)), nanowires begin to connect with a neighbor nanowire, and it appear a small nanoblock like a cone form. The inset in Fig. 2(e), it shows a clearly cone form. Annealing time was 1 hour, a nanowire is connected to other nanowires like a crooked bough, as shown in Fig. 2(f). Thus, the optimum growth condition of VO_2 nanowires on Al_2O_3 substrate is found to be at 670℃ and 30 min.

For the VO_2 nanowire grown at 670℃, the sharp first-order MIT jump near 347 K and the ohmic behavior above 347 K are exhibited (Fig. 3(a)). The electric field-induced first-order MIT is also measured (Fig. 3(b)). Jump of Current is 1.2 × 10^{-5} A to 9 × 10^{-4} A at V_{MIT}=21V and current follows Ohm's law in the larger voltage than V_{MIT}. This indicates that the nanowire has a component of metal. The MIT voltage can be controlled by varying the distance between electrodes of nanowire. The observed first-order MITs are attributed to breakdown of the critical on-site Coulomb interaction between electrons [4,11].

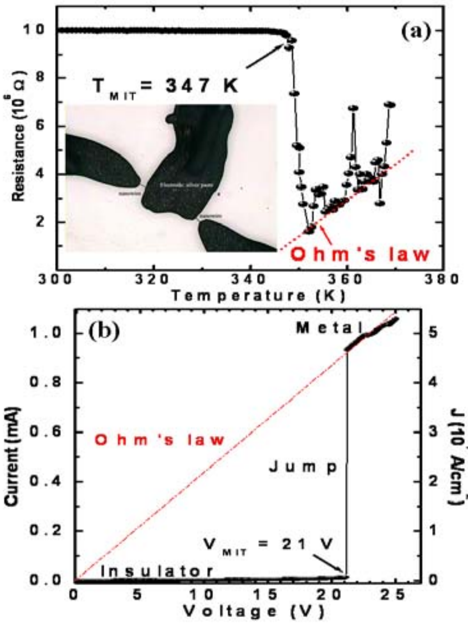

Fig. 3 (a) Temperature dependence of resistance of VO_2 nanowire of grown at 670 ℃. Inset shows electrode. (b) I-V measurement of VO_2 nanowire. It shows a sharp current jump when an electrical field is applied to nanowire with ~21 V.

In summary, we found conditions fabricating nanowires showing the first-order MIT which is far from the 1-D structural property. Furthermore, the crystalline nanowires with large resistnace are useful to a lot of device applications.

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