Materials Science in Semiconductor Processing 48 (2016) 79–84

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp

Electrical and optical properties of Ni-assisted grown single crystalline and transparent indium-tin-oxide nanowires

Hyunki Kim [a], Hyeong-Ho Park [b], Joondong Kim [a,*]

[a] Department of Electrical Engineering, Incheon National University, Incheon 406772, Republic of Korea
[b] Applied Device and Material Lab., Device Technology Division, Korea Advanced Nanofab Center (KANC), Suwon 443270, Republic of Korea

ARTICLE INFO

Article history:
Received 27 December 2015
Received in revised form
22 February 2016
Accepted 14 March 2016
Available online 22 March 2016

Keywords:
Optically transparent and electrically conductive
Single
Crystalline ITO Nanowires
Ni-assisted growth
Ni diffusion

ABSTRACT

Transparent and single crystalline indium-tin-oxide (ITO) nanowires (NWs) were grown by sputtering method. A thin Ni film of 5 nm was deposited before ITO sputtering. Thermal treatment forms Ni nanoparticles, which act as templates to diffuse Ni into the sputtered ITO layer to grow single crystalline ITO NWs. This Ni diffusion through an ITO NW was investigated by transmission electron microscope to observe the Ni-tip sitting on a single crystalline ITO NW. Meanwhile, a single crystalline ITO structure was found at bottom and body part of a single ITO NW without remaining of Ni atoms. This indicates the Ni atoms diffuse through the oxygen vacancies of ITO structure.

Rapid thermal process (RTP) applied to generate an initial stage of a formation of Ni nanoparticles with variation in time periods to demonstrate the existence of an optimum condition to initiate ITO NW growth. Modulation in ITO sputtering condition was applied to verify the ITO NW growth or the ITO film growth. The Ni-assisted grown ITO layer has an improved electrical conductivity while maintaining a similar transmittance value to that of a single ITO layer. Electrically conductive and optically transparent ITO nanowire-coated surface morphology would provide a great opportunity for various photoelectric devices.

1. Introduction

Indium-tin-oxide (ITO) material is widely used in transparent electronics due to its excellent electrical conductivity and optical transparency. These optical and electrical benefits induce practical applications in solar cells [1,2], displays [3], transparent electronics [4] and photodetectors [5,6].

Design of nanoscale structures is a promising approach for photoelectric devices due to the spontaneously enlarged light-reactive surface area along to the nanostructures. For an electrical conductive metallic nanowire, which demonstrated a strong possibility for a nanoscale interconnection [7] with the huge amount current delivery performance. Meanwhile, a tiny scale electrical conducting nanowire has been used for field emitters [8] and microscopy tips [9]. In spite of the electrical excellence of metallic nanowires, the optically non-transparent property limits the use of metallic nanowires in photoelectric applications. Metallic NWs have been applied for transparent electrodes to resolve optical transparency hurdle by sparse distribution of metallic NWs on a surface [10].

And therefore, transparent and electrical conductive nanowire synthesis is a promising approach to satisfy the optical and electrical demands simultaneously for photoelectric device applications. Recently, transparent ITO material has been investigated to grow ITO nanowires by sputtering [11–14], vapor transport [3,15], vacuum evaporation [14], Epitaxial growth [16], and pulsed laser deposition [17], and they were applied for light-emitting devices [17], solar cells [11] and hydrophobic applications [18].

Although, many possible growth methods ITO NWs were reported, few are known for the growth mechanism by using the metal-template method. Additionally size-limited area or high temperature process for ITO NW growth critically limits the ITO NW integration into a device [3,15,16]. Herein, we report metal-assisted ITO nanowire growth for a large scale area. Ni was used as a template medium to react upcoming sputtered ITO nanoparticles. Ni diffusion through the deposited ITO remained a single crystalline ITO NW and Ni was moved to a tip of ITO NW. We have modulated the ITO deposition conditions and Ni heat-treatment to find an optimum condition of Ni-assisted ITO NW growth condition.

2. Experimental details

Ni as a template was deposited on SiO_2-coated Si and glass substrates for ITO NW growth. 5 nm-thick Ni was DC-sputtered at

* Corresponding author.
E-mail address: joonkim@incheon.ac.kr (J. Kim).

http://dx.doi.org/10.1016/j.mssp.2016.03.016
1369-8001/

a room temperature in an Ar atmosphere condition by flowing condition of 50 sccm. To form Ni nanostructures, rapid thermal process (RTP) was applied with modulation in time (5–30 min) at a processing temperature of 550 °C. ITO deposition was performed by DC-sputtering in variation of sputtering power (1.23–3.70 W/cm^2) with modulation in time (5–30 min) and processing temperature (300–600 °C). The ITO morphological changes were observed by using field emission scanning electron microscope (FESEM, JEOL, JSM_7800F) with 10 kV of field voltage, using an SE2 detector. A field emission transmission microscope (FETEM, JEOL, JEM-2100F) was used to observe the crystalline structure of a single ITO NW. To prepare a TEM sample, the ITO NWs were cropped from the ITO NW grown substrate and dispersed on a TEM copper grid with a carbon film support. Optical transparency was measured by a UV–visible spectrophotometer (Shimadzu, UV-1800) from the ITO coated glass samples.

3. Results and discussion

5 nm-thick Ni film was RTP-treated at 550 °C for 10 min before ITO sputtering. To observe the morphological changes, ITO sputtering conditions were modulated in variation of sputtering power density (1.23–3.70 W/cm^2) and time (5–20 min). During the ITO sputtering process, 600 °C heating was supplied to a substrate holder. SEM images are shown in Fig. 1 for cross-sectional (left) and top (right) views. For a sputtering condition of 1.23 W/cm^2 for 10 min (Fig. 1a), very short and tiny nanoscale structures were formed without appearing of ITO NWs. Meanwhile, an extended sputtering time (20 min) with a same sputtering power density (1.23 W/cm^2) significantly changed the morphologies to give very sharp-tip shaped ITO NWs (Fig. 1b). This distinctive observation indicates that the growth of ITO NWs is strongly controlled by ITO deposition time and thickness by comparing Fig. 1(a) and (b). At a fixed sputtering power density, the sputtering thickness is proportional to the time period. At a power density of 1.23 W/cm^2, we observed ITO deposition thickness of 87.8 nm and 170 nm for sputtering time of 10 min and 20 min, respectively.

In order to investigate the effect of ITO thickness and sputtering condition for ITO NW growth, we applied high power density conditions. A double power density (2.47 W/cm^2) was given for sputtering time for 10 min and 20 min. As seen in Fig. 1(c), 10 min deposition time gave a thickness of 157.6 nm, close to that of Fig. 1 (b) to produce similar ITO NW grown surface. With an extended sputtering time by 20 min, the ITO deposited thickness was increased by 315.1 nm as shown in Fig. 1(d). From this condition, thick and short ITO NWs were appeared.

For further experimental demonstration of ITO sputtering condition for ITO NW growth, a higher sputtering power density (3.70 W/cm^2) was taken for 5 min and 10 min. The ITO deposited thickness was obtained to be 124.8 nm for 5 min (Fig. 1e) and 224.2 nm for 10 min (Fig. 1f). Both cases seem to be out of the condition of ITO NW growth but thick and short nanostructure formation. To consider the sputtering ratio of 8.5–10.75 nm/min (Fig. 1b, c, and d for ITO NW grown condition), the high sputtering power density of 3.70 W/cm^2 induces a fast deposition ratio over 20 nm/min, which is not in the range of ITO NW growth but in the ITO film formation. A fast ITO sputtering supply readily causes large size nanostructures to reduce surface tension resulting in a film type formation instead of NW growth [19].

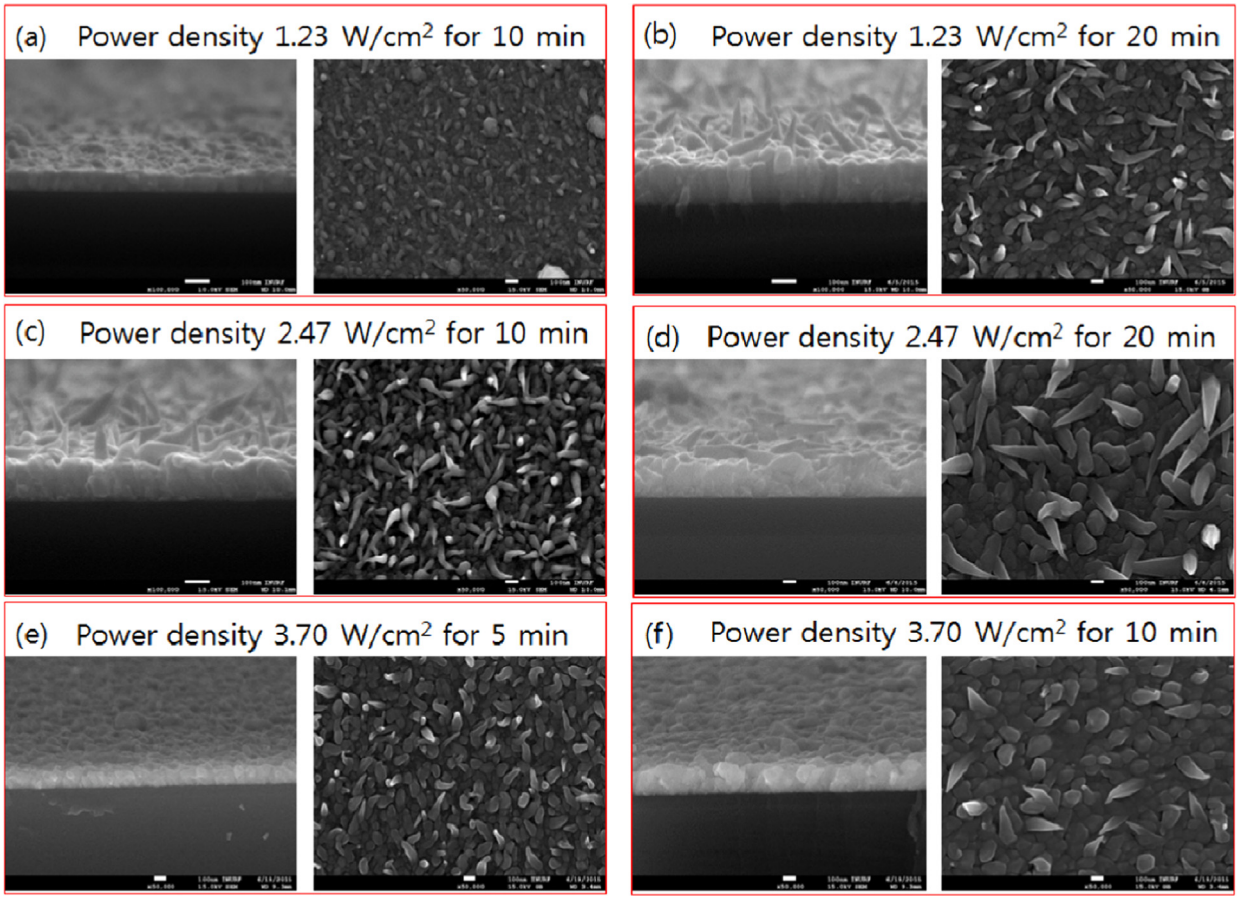

Fig. 1. SEM images for morphological changes of the sputtered ITO layers. Left and right images are a cross-sectional and a top view image for each sputtering condition. Scale bars are 100 nm in all images.