Fabrication and Electrochemical Investigation of Sandwich-like Si/V_2O_5/Si on Copper Substrate by Layer-by-Layer Approach

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Abstract: The fabrication and the structural, morphological and electrochemical analyses of sandwich-like Si/V_2O_5/Si thin film onto Cu substrate are reported here. The sandwich-like thin film, aimed at reducing the instability triggering frequency concerns in Si-based thin films, is prepared via Radio Frequency (RF) Magnetron Sputtering Technique.

Keywords: Silicon, vanadium pentaoxide, sandwich like, thin film, magnetron sputtering.

1. Introduction

Silicon is the 8th most typical element in the universe, though seldom occurs in nature as the pure free element which is more widely spread in dust, sands, planetoids and planets, as diverse formations of silica (SiO_2). Also, silicon is the second most abundant element after oxygen (45.5%), more than 27 % of the crust by mass in Earth's crust [1]. Silicon is the prevalent ingredient of semiconductor devices, solar cells, and battery applications which are called on energy storage technologies, as well [2]. Pristine silicon is a nonconductor, and owns no free electrons; all the electrons are firmly connected to adjacent atoms. The doping process of pure silicon makes it conductive by combining silicon with boron or phosphorous elements [3].

On the other hand, a transition metal oxide, V_2O_5 contains a famous semiconductor-to-metal phase transition, which has drawn substantial attraction owing to its industrial applications in optical switching and electrochromic devices [4] and cathode or anode electrodes for Li-ion batteries [5,6] attended by an abrupt change in its resistivity and near-infrared transmission [7]. This feature makes it interesting for intelligent windows, resistive memories and switches in microelectronics.

This paper reports on structural and electrochemical features of Si/V_2O_5/Si thin film deposited via RF magnetron sputtering method on copper substrate. Energy dispersive X-ray spectrometer (EDX), Scanning Electrode Microscope (SEM) were used for surface and structural characterization of the film, whereas cyclic voltametry (CV) measurements were employed for electrochemical features.

2. Experimental

2.1. Production of the Binder- Free and Nanosandwich Si/ V_2O_5 /Si Thin Film

The copper-foil substrate was cleaned with ethanol and after that coated using the RF magnetron sputtering technique. Si was sputtered onto substrates from boron doped Si target. The blast chamber was supplied with Ar gas; both to remove the impurities on the substrate surface before the coating process and on the radiation discharge plasma sideAr ion was bombarded on the target material using the electric field, allowing the target material to be sputtering and the working pressure of the magnetron sputter was set at 1.1 Pa. The substrate spin rate of 6 rpm and the distance between the target and substrate were adjusted at 80 mm. The sputtering process was conducted using 80 W constant RF power.

V_2O_5 target was used in the modification process with a sandwich-like V_2O_5 interlayer between the Si layers to be produced. The distance between the target and substrate, base pressure and substrate rotation parameters are the same as the procedure of deposition of the Si, and the working pressure is fixed at 1.7 Pa. The sputtering process was arranged to 140 W constant RF power. V_2O_5 interlayer of 15Si/V_2O_5/Si, 30Si/V_2O_5/Si, and 45Si/V_2O_5/Si thin films was deposited for 15, 30, and 45 minutes, respectively. Fig.1 shows a schematic representation of the RF magnetron sputtering method and sandwich-like thin film electrodes.

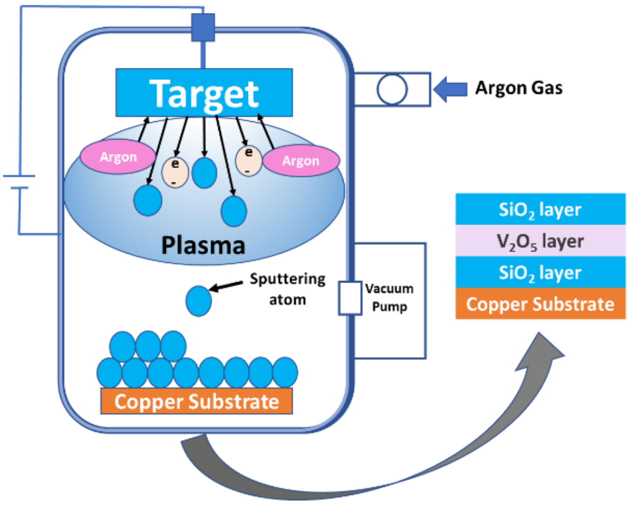

Fig. 1. Illustration of RF magnetron sputtering technique.

The thickness of the layers deposited onto the copper substrate was controlled by exploiting an Inficon SQM-160 model thin film deposition monitor throughout the RF magnetron sputter. The quartz crystal microbalance film thickness was calibrated simultaneously with cross-sectional SEM photographs.

2.2. Characterizations

The field-emission Scanning Electron Microscopy (SEM) (FEI Quanta FEG 250) was carried out to characterize the surface morphologies of the prepared thin films deposited on copper-foil substrates. The Energy Dispersive Spectroscopy (EDX) equipped with the SEM was used to determine the surface compositions of the sandwich-like thin films.

Electrochemical characteristics were examined by exploiting a potentiostat/galvanostat (CHI760E) on the standard electrolytic cell of three electrodes (half cell) at room temperature (24 ± 1 °C). The working electrode was the different thichness of interlayer of Si/V2O5/Si thin films on Cu foil, and the counter electrode was platinum. The reference electrode was Ag/AgCl with saturated KCl solution and 1 M lithium perchloride in propylene carbonate was used as the electrolyte. The measurements of the electrodes characterized by exploiting Cyclic Voltammetry (CV) were in the potential range of −1.2 ~ 0.4 V under a scan rate of 50 mV/s.

3. Results and Discussion

SEM was examined with photographs of the surface of each of the as-deposited sandwich-like thin films. These photographs could benefit determine any distinctions between the films according to morphological features. SEM images of the Si/V_2O_5/Si thin films are demonstrated in Fig. 2, an amorphous structure of the thin films produced on the surface of Cu foil by the RF magnetron sputtering method. Compared to the 15Si/V_2O_5/Si (Fig. 2a, b) thin film, the surface of produced 30Si/V_2O_5/Si (Fig. 2c, d) and 45Si/V_2O_5/Si (Fig. 2e, f) seemed to be more rugged with more spherical particles. The further ruggedness on the surface and protective layer provided by increasing the thickness of the V_2O_5 interlayer may aid reduce of the volume expansion and contraction of the Si surface for electrochemical capacitive analyses.

The EDX spectrum of the sandwich like thin films indicated the presence of elements of Si, O, V, and Cu. The main elements of the structure were Si, O, and V. Cu element were due to the copper-foil substrate. In consequence, the deposited Si/V_2O_5/Si on copper substrate was effectively produced using the RF magnetron sputtering technique (Fig. 3).

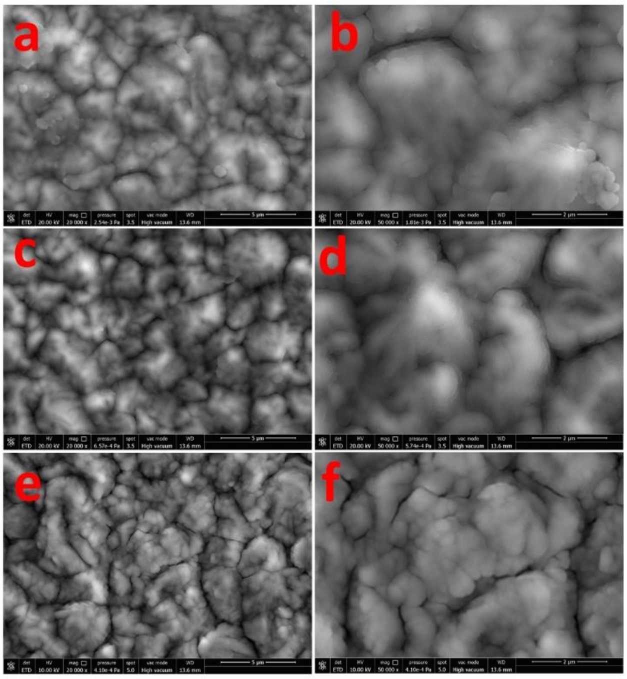

Fig. 2. Typical SEM images showing surface topography of (a, b) 15Si/V_2O_5/Si, (c, d) 30Si/V_2O_5/Si, and (e, f) 45Si/V_2O_5/Si thin films at 20,000X and 50,000X magnifications, respectively.

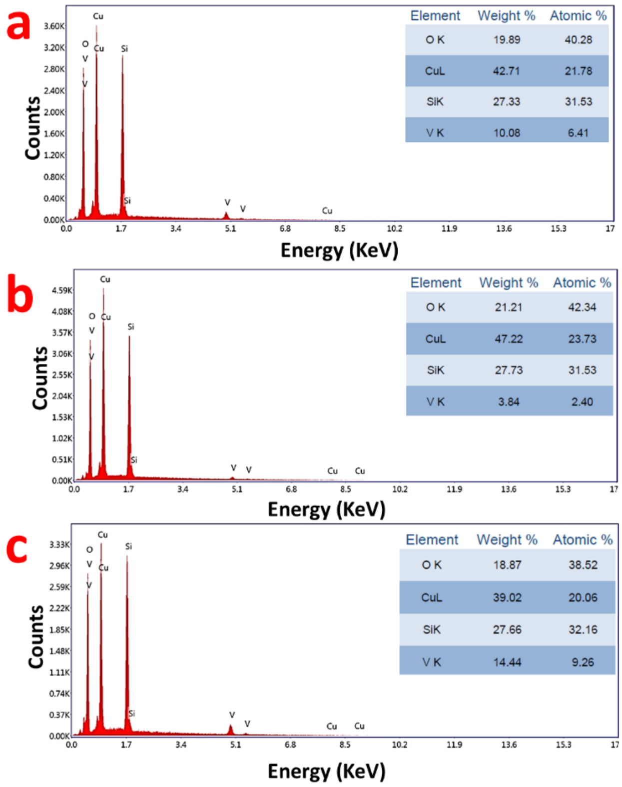

Fig. 3. EDX spectra of as-deposited (a) 15Si/V_2O_5/Si (b) 30Si/V_2O_5/Si and (c) 45Si/V_2O_5/Si onto Cu foil thin film electrodes.

Figure 4 indicates CVs of Si/V_2O_5/Si thin films at different deposition times of the V_2O_5 interlayer at a scan rate of 50 mV/s. The 15Si/V_2O_5/Si has not any oxidation or reduction peak in the range of −1.2 ~ 0.4 V. The 30Si/V_2O_5/Si shows a reduction peak as compared to 15Si/V_2O_5/Si. The current values of Si/V_2O_5/Si thin films were decreased in increasing thickness of the V_2O_5 interlayer indicating decreasing conductivity with the thickness of V_2O_5 metal oxide. On the other hand, 45Si/V_2O_5/Si thin film indicates reversibility by owning an oxidation peak of −0.3 V and a reduction peak of 0 V in the voltage window.

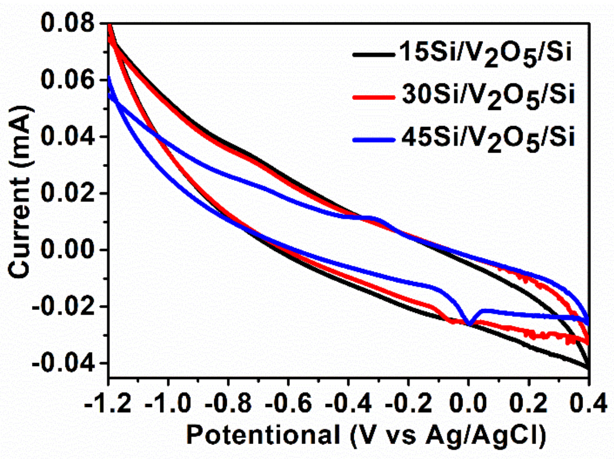

Fig. 4. CV of sandwich-like Si/V_2O_5/Si thin films.

4. Conclusions

In summary, sandwich-like Si/V_2O_5/Si thin films have been prepared on a Cu foil by using an RF magnetron sputtering technique without organic additives, conductive agents, binder chemicals, and substrate pre-treatment. The CV shows that 45Si/V_2O_5/Si can be a candidate for good pseudocapacitive behaviour, due to the increasing V_2O_5 interlayer, large surface area, ordered arrangements, reversibility, and top-down structures, which provide more capacity for accommodating the electrolyte ions and direct paths for the electrolyte ion intercalation/deintercalation process.

5. References

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