Materials Research Bulletin 62 (2015) 177–183

Contents lists available at ScienceDirect

Materials Research Bulletin

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

Thickness and UV irradiation effects on the gas sensing properties of Te thin films

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ARTICLE INFO

Article history:
Received 26 April 2014
Received in revised form 29 October 2014
Accepted 11 November 2014
Available online 13 November 2014

Keywords:
A. Thin films
A. Semiconductors
B. Vapor deposition
C. X-ray diffraction
D. Electrical properties

ABSTRACT

In this research, tellurium thin films were investigated for use as hydrogen sulfide gas sensors. To this end, a tellurium thin film has been deposited on Al_2O_3 substrates by thermal evaporation, and the influence of thickness on the sensitivity of the tellurium thin film for measuring H_2S gas is studied. XRD patterns indicate that as the thickness increases, the crystallization improves. Observing the images obtained by SEM, it is seen that the grain size increases as the thickness increases. Studying the effect of thickness on H_2S gas measurement, it became obvious that as the thickness increases, the sensitivity decreases and the response and recovery times increase. To improve the response and recovery times of the tellurium thin film for measuring H_2S gas, the influence of UV radiation while measuring H_2S gas was also investigated. The results indicate that the response and recovery times strongly decrease using UV radiation.

1. Introduction

Tellurium is a P-type semiconductor with narrow band gap and a gap energy of 0.35 eV which makes it ideal for use in thin film transistors [1], gas sensors [2–4], optical information storage [5] and shields in passive radiative cooling [6]. Recently, it has been shown that the tellurium thin film is sensitive to toxic gases like H_2S [7]. Hydrogen sulfide is a toxic and corrosive gas which is formed in coal mines, oil and gas industries, chemical products plants, and the sewers. Exposure to small amounts of this gas (less 50 ppm) causes headache, poor memory, loss of appetite and irritability, while exposure to large amounts (most of 500 ppm) will cause death after 30–60 min [8]. So far, various semiconductor metal oxides have been produced for detecting H_2S gas such as SnO_2, WO_3, and In_2O_3 [9–11] and usually operating at temperatures above 150 °C leading to shorten the life of the sensor. Measuring gas through semiconductor metal oxide depends upon parameters like thickness of the thin film, deposition temperature, and the substrate material. Tsiulyanu et al. [3,12] have shown sensors based on tellurium thin films exhibit high sensitivity to NO_2, CO and $C_3H_7NH_2$ at room temperature in the ppm concentration range. Bhandarkar et al. [7] have investigated the effect of different substrates, different deposition temperatures as well as post-deposition annealing on the gas sensitivity of thermally evaporated Te films. These studies indicated that the film deposited on a glass substrate at 100 °C showed the maximum sensitivity towards gases such as H_2S and NO_2. Many approaches have been studied to improve the sensitivity and response and recovery time of metal oxide gas sensors, such as noble metal doping [13], transition-metal oxide incorporation [14] and light irradiation [15]. Comini et al. [16] have shown that exposure of UV radiation results in decrease in the response and recovery time of tin oxide gas sensor at low temperature with no poisoning effect when NO_2 come in contact. Mun et al. [17] have shown a significant enhancement in the response of the ZnO nanosheets to NO_2 gas by UV irradiation which was attributed to the increase in resistance due to the photo-generation of electrons and holes. So far, the effect of UV irradiation on the sensitivity of Te-based sensors has not been investigated. In this research, the influence of the thickness of the tellurium thin film on detecting H_2S gas and also the influence of the film temperature and UV radiation while measuring H_2S gas have been studied.

2. Experimental details

Tellurium thin films with thicknesses of 100, 200, and 300 nm measured by Quartz digital thickness gauge, were deposited on Al_2O_3 substrate by thermal evaporation of pure tellurium in a

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http://dx.doi.org/10.1016/j.materresbull.2014.11.027
0025-5408/

tungsten crucible. Substrates were cleaned for 30 min by alcohol and acetone in ultrasonic bath. The initial pressure of the vacuum chamber and the temperature of substrate while depositing were respectively 3×10^{-5} mbar and 100 °C. The growth rate of the film and the deposition area were 5 nm/s and 100 mm^2, respectively. Gold electrodes were deposited on the surface of film through thermal evaporation and copper wires were attached to them by silver paste. The crystal structure of the films was characterized through X-ray diffraction (XRD) using a Philips-PW 1800 with Cu (Kα) (40 kV, 30 mA) radiation (λ = 0.15406 nm). The morphology of the films surface was determined by scanning electron microscope (SEM) using a Hitachis-4160. Sensor response to various concentrations of H_2S gas was studied in a container with a volume of 250 cm^3 which was connected to a gas flow system. A mass controller controls the concentration of H_2S gas. The electrical resistance of the sensors was measured by a multimeter as a function of time. Gas limit detection was performed for the films with different thicknesses and at different environment temperatures. The sensors were also exposed to UV radiation while detecting H_2S gas. LED light source with a wavelength of 365 nm (power density of 1 W cm^{-2}) is applied to Te thin film for three minutes in the air during the recovery time. The distance between the UV light and sample is two centimeter. The mechanism of gas detection was investigated by Raman spectroscopy technique. The spectra were recorded before and after exposure of samples to the gas. Raman spectra of the films were recorded in back scattering geometry with a spectral resolution of 3 cm^{-1}. The 785 nm line of Ar^+ laser was used for excitation.

3. Results and discussion

XRD patterns of tellurium films with different thicknesses are shown in Fig. 1. In this figure, the peaks denoted with star are related to Al_2O_3 substrate. At 100 nm Te thickness peak of low intensity is observed the Bragg angle at 27.77° which is related to Te (1 0 1) with hexagonal crystal structure. The calculated lattice parameters are: $a = 0.4457$ nm and $c = 0.5927$ nm, which are in accordance with the JCPDS data (JCPDS card no. 36-1452). At 200 nm, in addition to Te (1 0 1), another peak corresponding to Te (1 0 0) appears at 23.15°. Finally, besides Te (1 0 0) and Te (1 0 1), a

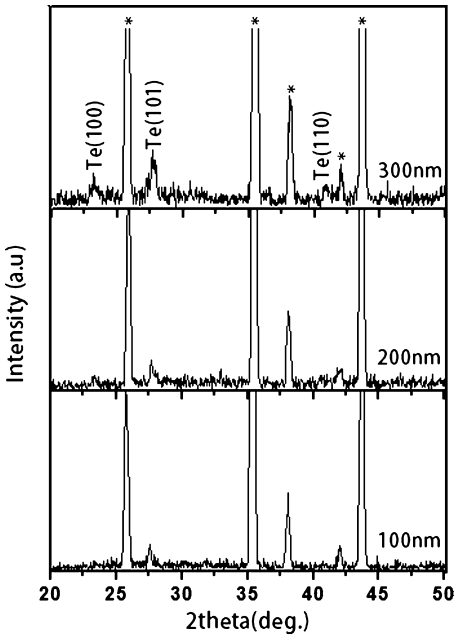

Fig. 1. XRD patterns of Te films with different thicknesses.

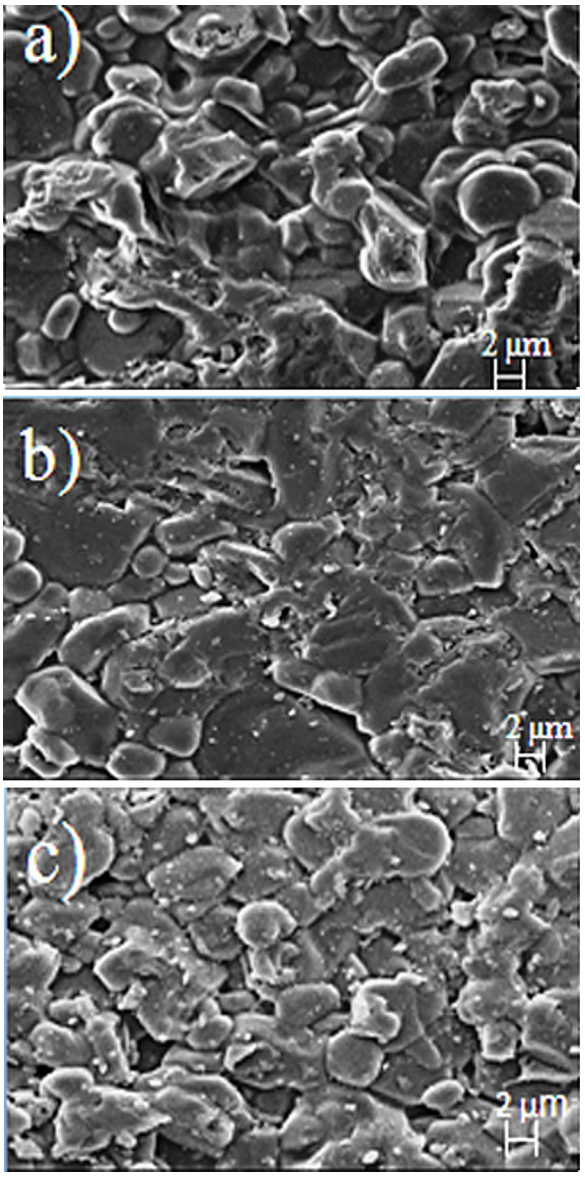

Fig. 2. SEM images of Te films with different thicknesses: (a) 100, (b) 200 and (c) 300 nm.

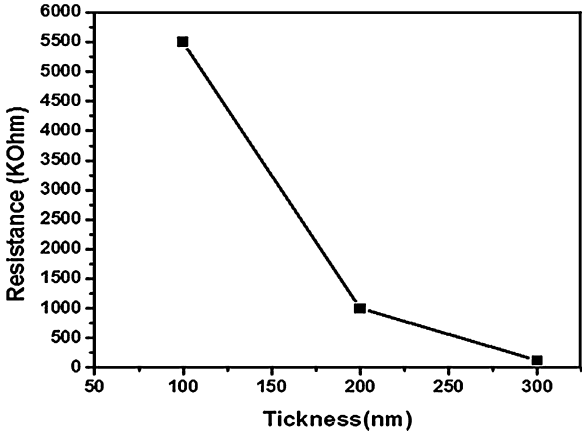

Fig. 3. Resistance of Te films before expose to H_2S.