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Vacuum Evaporated V_2O_5 Thin Films for Gas Sensing Application

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Abstract: V_2O_5 thin films have been widely considered as good candidates for their use as environmental gas sensors for detecting pollutant gases like carbon monoxide, carbon dioxide, hydrocarbons, ammonia and nitrogen oxides. V_2O_5 thin films were prepared by vacuum evaporation technique and the gas sensing properties of V_2O_5 thin films were studied. When the reducing gas is exposed to the sensing element, it reduces the resistance of the material, which confirms the typical characteristic of a n-type material.
Keywords: V_2O_5; Thin films; Vacuum evaporation; Gas sensor.

Introduction:

The interest for high-performance thermoelectric materials has increased in the last decades due to the development of new deposition methods with which one can tailor the properties by structural engineering at atomic level [1]. Vanadium pentoxide (V_2O_5) thin films are of considerable scientific and technological interest. V_2O_5 crystallizes in an orthorhombic, weakly bonded layered structure, with vanadium surrounded by six oxygen atoms forming a strongly distorted octahedron unit. It is the most stable compound in the V-O system, exhibiting highly anisotropic electrical and optical properties due to its orthorhombic structure [2]. Besides, it is the most important metal used in metal oxide catalysis, due to the oxidation states of the vanadium atoms varying from two to five, and easy conversion between oxides of different stoichiometry [3]. Nitrogen oxide NO_x (NO or NO_2) is mainly released from combustion facilities and automobiles. There have been lots of efforts on developing a variety of NO_2 gas sensors such as electrochemical sensors, SAW sensors and polymer sensors [4]. Recently, metal oxide semiconductor NO_2 gas sensors have been studied extensively because of their simple fabrication processes and low cost. Especially, V_2O_5 is one of good materials for NO_2 sensing due to its high sensitivity and good selectivity to low concentration NO_2 gas. The focus of sensor development concerns the modification of surface structure of materials that provide increased sensitivity, selectivity and stability.

Experimental:

V_2O_5 thin films were prepared on to Corning 7059 glass substrates by vacuum evaporation of pure V_2O_5 Powder (purity 99.99% obtained from MERCK) from an electrical heated molybdenum boat kept at ~ 1823 K in a vacuum better than 8 x 10^{-6} Torr. A Hind High Vacuum 12A4 Coating unit was used for the deposition of the experimental films. A diffusion pump backed by a rotary pump was employed to produce the ultimate pressure of 3 x 10^{-6} Torr. Well cleaned Corning 7059 glass substrate along with suitable masks were mounted on a copper holder which was fixed on a tripod in the beljar. The system was allowed to reach the ultimate vacuum. When the power was fed to the boat, the material in the boat evaporated and the vapors reacted with the oxygen gas leading to film deposition on the substrate [5]. The deposition rate observed by a quartz crystal thickness monitor was 10 A^0/sec. The thickness of the films investigated was about 4000 A^0.

Results and Discussion:

The as deposited V_2O_5 films have uniform yellow colour similar to those prepared by other techniques. Such yellow color could indicate that vanadium was incorporated as V^{+5} in V_2O_5 lattice, because, it is known that V^{+4} presents a brown or black color. However, it was shown that, films prepared by thermal evaporation had light green tint that turned yellow upon annealing in O_2 atmosphere. The conductance of the sensor in dry air was measured by means of conventional circuitary by applying constant voltage and measuring the current by picoammeter. The conductance was measured both in the presence and absence of test gas. The gas response (s) is defined as the ratio of change in conductance in gas to air to the original conductance in air

$$S = (G_g – G_a) / G_a \text{ ----------------- } (1)$$

V_2O_5 conductometric sensors were mounted on an electric heater. Gas response measurements of the devices were performed in a stainless steel test chamber made from Teflon, which was sealed in a quartz lid. The heater was controlled by a regulated DC power supply providing different operating temperatures. The total flow rate was kept constant at 50 sccm and dry synthetic air was used as the reference gas. Subsequently, the device was exposed to sequences of different concentrations of NO_2 for several hours. In the V_2O_5 sensor, change in the oxygen balance of the oxide layer leads to a variation in its conductance. In the case of an oxidizing gas (NO_2), reactions directly take place on the oxide surface. During the interaction process, molecules consume conduction electrons and subsequently increase the depletion region at the surface and the resistivity of the sensor increases as presented below.

V_2O_5 films were exposed to different concentrations of NO_2 gas at various temperatures. The desired gas concentration is obtained by mixing the appropriate flows of gases by means of mass flow controllers. The films are generally heat treated before exposure to different gasses because it produces contacts between grains, many of which are between grains having different crystal structures. When both the films are exposed to NO_2 gas, the dc electrical resistance of the film dramatically increased. Since V_2O_5 is an n type semiconductor, its electrical behavior upon exposure of NO_2 oxidizing gas can be explained by a decrease of conduction carrier density. The amount of oxygen ions available on the V_2O_5 surface increases at the operating temperature. The adsorbing NO_2 molecules interact directly with the adsorption sites at the oxide surface. Therefore the interaction between the film and NO_2 is as follows;

$$NO_2 + e^- \rightarrow NO^{2-} (ad)$$

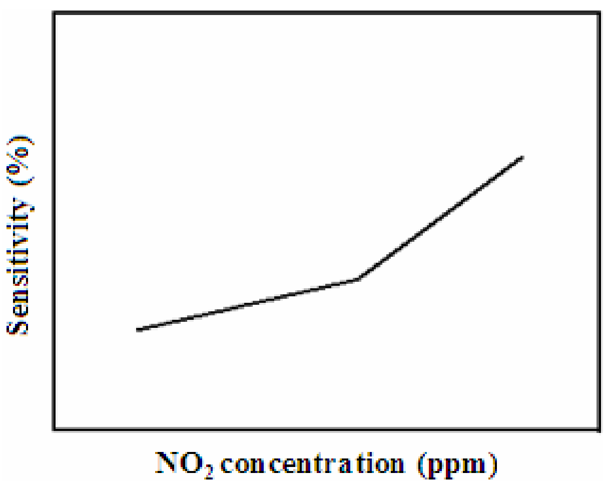

Fig. 1 NO_2 concentration as a function of sensitivity

The sensitivity of the prepared V_2O_5 thin films for various gas concentrations can be calculated from the equation defined as follows:

$$S = R_a/R_g \text{ ------------------- } (2)$$

where S is the sensitivity, R_a is the resistance of a sensor in air medium and R_g is the resistance of a sensor in a test gas medium. The calculations were made by taking the resistance values at the time after which there was no significant decrease in the resistance.The results of the sensing experiments were graphically presented in Fig.1. When the reducing gas is exposed to the sensing element, it reduces the resistance of the material, which confirms the typical characteristic of a n-type material. It is clearly observed that, as the test gas concentration was increased the resistance decreased drastically.

Conclusions:

V_2O_5 thin films were exposed to different concentrations of NO_2 gas at various temperatures and the sensitivities of the films were recorded at various temperatures. If a sensor exhibits a specialized response to one gas only, then it can be used to detect that gas since there will be no interference by other gases. The ultimate goal is to create a useful chemical gas sensor that can be used to determine the concentration of one gas in air at the lowest concentration possible before it becomes dangerous to human health.

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