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Fabrication of ZnO-Based Ethanol Gas Sensors Using Aerosol-Assisted Atmospheric Pressure Plasma

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Abstract

This contribution studies a fast and simple method for depositing metal oxides by using an aerosol-assisted atmospheric pressure plasma process. ZnO films were deposited on arbitrary substrates and characterized by scanning electron microscopy and X-ray diffraction. In addition, ZnO-based gas sensors were tested for the detection of ethanol gas at concentrations between 100 ppb to 1000 ppb. In this study, ZnO was adopted as an example of metal oxides that can be deposited but it is possible to produce various metal oxides using the aerosol-assisted atmospheric pressure plasma process.

Key words: atmospheric pressure plasma jet, aerosolization, pyrolysis, metal oxides, gas sensors

Introduction

Atmospheric pressure plasma has been widely used for a variety of applications, such as surface modification, healthcare, and industrial processes, due to its combination of simplicity and low cost. Recently, it was shown that atmospheric pressure plasma could be successfully used for the deposition of polymers, metal nanoparticles, metal oxides, carbon nanotubes, and graphene [1-3]. In this work, metal oxide films were directly deposited on substrates with interdigitated electrodes by an aerosol-assisted atmospheric pressure plasma jet (APPJ) and their gas sensing properties were investigated. Our approach enabled a series of processes from synthesis of sensing materials to fabrication of gas sensors to be carried out simultaneously.

Experimental Details

The APPJ composed of three quartz tubes is schematically described in Fig. 1. Copper tape used as power and ground electrodes was wrapped around quartz tubes, each having an inner diameter of 1.4 mm and an outer diameter of 3.0 mm such that the center-to-center distance between two adjacent quartz tubes was 3.0 mm. Ultra-high purity argon and zinc acetate dihydrate solution were used as the discharge gas and precursor, respectively. The precursor solution was aerosolized by a commercial nebulizer, where argon was used as the carrier gas to feed the aerosolized precursor into the APPJ. After the deposition of films for 30 min, the sample was heated at 500 °C for 2 h.

Results and Discussion

The films consisted of micro and nano-sized particles were formed by the aerosol-assisted APPJ while the films were barely deposited

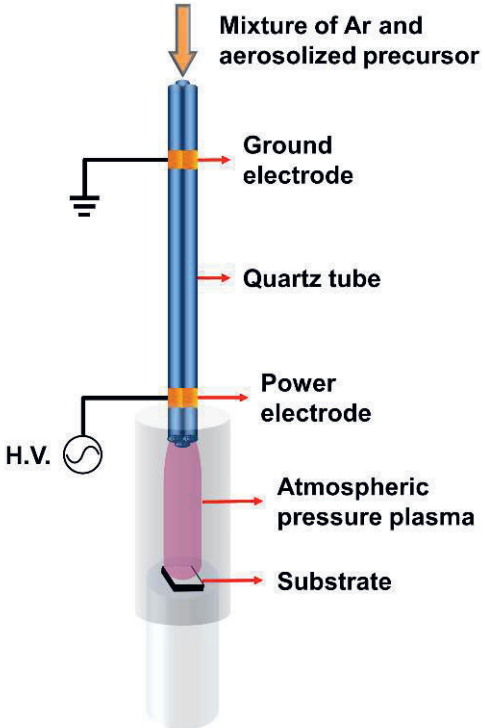

Fig. 1. A schematic diagram of the aerosol-assisted APPJ deposition system.

without plasma. As shown in Fig. 2(a) and (b), most of the particles have spherical shape before pyrolysis and the adjacent particles coalesce together after pyrolysis. Fig. 2(c) provides the XRD pattern of the films deposited on Si. Various diffraction peaks are observed after pyrolysis and all of the peaks in the obtained spectrum are well indexed to hexagonal ZnO phase (JCPDS card No. 36-1451), indicating that the films were completely converted into ZnO upon pyrolysis at 500 °C.

The ethanol sensing properties of the prepared ZnO films were studied at the operating temperature of 400 °C under a dry condition as shown in Fig. 3. The sensor response is defined as eq. (1), where R_a and R_g denote the electrical resistance upon exposure to air and the analyte gas, respectively.

$$Response\ (\%) = \frac{|R_g - R_a|}{R_a} \times 100 \quad (1)$$

When ZnO is exposed to ethanol gas, ionized oxygen anions adsorbed onto the surfaces of ZnO oxidize ethanol gas and the remanent electrons are injected into ZnO, which induces a decrease in its resistance. Consequentially, there was a monotonic increase in responses with increasing ethanol concentrations ranging from 100 ppb to 1000 ppb.

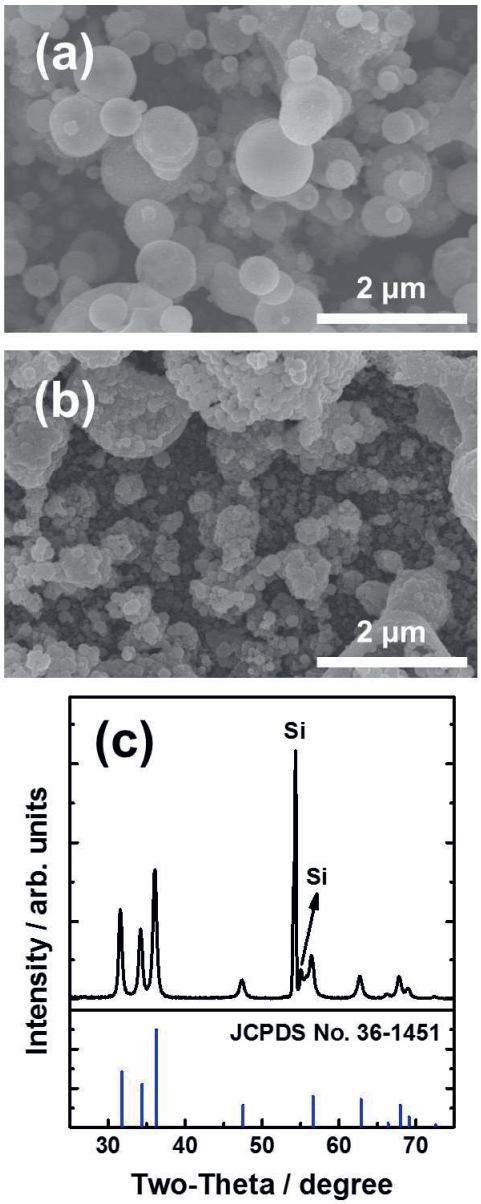

Fig. 2. SEM images of the deposited films (a) before pyrolysis and (b) after pyrolysis at 500 °C for 2 h. (c) XRD pattern of the deposited films after pyrolysis at 500 °C for 2 h.

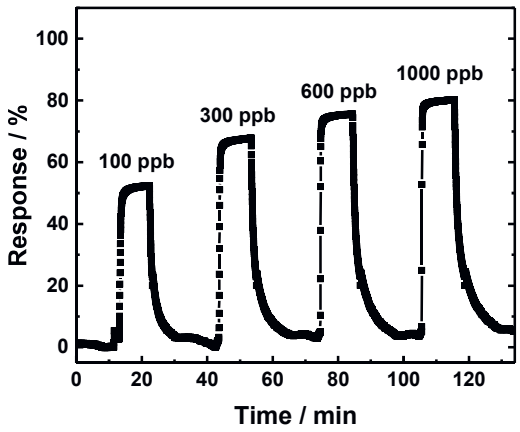

Fig. 3. Gas sensing performance of ZnO exposed to 100 ppb, 300 ppb, 600 ppb, and 1000 ppb ethanol gas at 400 °C under a dry condition.

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