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Low power micro-gas sensors using mixed SnO_2 nanoparticles and MWCNTs to detect NO_2, NH_3, and xylene gases for ubiquitous sensor network applications

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ABSTRACT

Using mixed SnO_2 nanoparticles with 1 wt.% MWCNTs sensing materials, NO_2, NH_3, and xylene gas sensors were fabricated on micro-platforms. A micro-platform consists of micro-sensing electrode and micro-heater on 2 μm thick SiN_x membrane. The fabricated gas sensors were characterized to NO_2, NH_3, and xylene gases, respectively, as a function of concentration at 300 °C and temperature from 180 °C to 380 °C at constant concentration. The measured highest sensitivities for the NO_2, NH_3, and xylene were 1.06 at 1.2 ppm and 220 °C, 0.19 at 60 ppm, and 220 °C, and 0.15 at 3.6 ppm and 220 °C, respectively. So, it was found that 220 °C was the optimum temperature to have the best sensitivities. From these results, mixed SnO_2 nanoparticles with 1 wt.% MWCNTs showed good sensitivity and selectivity at low power operation below 30 mW. Fabricated micro-gas sensors could be used for ubiquitous sensor network applications to monitor environmental pollutants in the air.

1. Introduction

Recently, ubiquitous sensor networks for monitoring environmental pollutants in air using gas sensors have been actively researched [1,2]. Gas sensors are one of the most important parts of ubiquitous sensor network systems, particularly since low power consumption and high sensitivity and selectivity are key requirements for the sensor node [3,4]. The response and recovery times of many environmental gases indicate that those gases may be detected more quickly at controlled temperatures than at room temperature [5,6]. Ideally, the sensors would be able to operate at low power levels for at least a few months at a time for portable applications in ubiquitous sensor nodes [7]. Some studies have shown power consumption levels for gas sensors of 20 mW at 250 °C and 5 ppm for NO_2, and 80 mW at 2% for H_2 [8,9]. Additionally, in order to realize these objectives, many sensing materials are presently being studied. Specifically, SnO_2 particles and multi-walled carbon nanotubes (MWCNTs) have been investigated due to their special geometries and surface features [10,11].

In this paper, four types of micro-platforms for micro-gas sensors were designed and fabricated for low power consumption characteristics [12,13,39]. We studied and compared the gas sensing properties of mixed SnO_2 nanoparticles and MWCNTs. The sensitivities to NO_2, NH_3, and xylene gases as functions of their concentrations were measured at 300 °C in air. We also investigated the temperature dependence of the fabricated micro-gas sensors to determine the optimal low power operating conditions that resulted in high sensitivities to the NO_2, NH_3, and xylene gases.

2. Experimental procedures

2.1. Fabrication of micro-platforms with heaters and sensing electrodes for detection of gases

A Si substrate (1 0 0) was prepared for the production of a low stress 2 μm thick SiN_x film that was deposited using a low pressure chemical vapor deposition process (LPCVD). A patterned platinum (Pt) film was used for the micro-heater in order to increase the temperature and to better activate the sensing materials. Tantalum (Ta) was used for the adhesive layer between the SiN_x and Pt.

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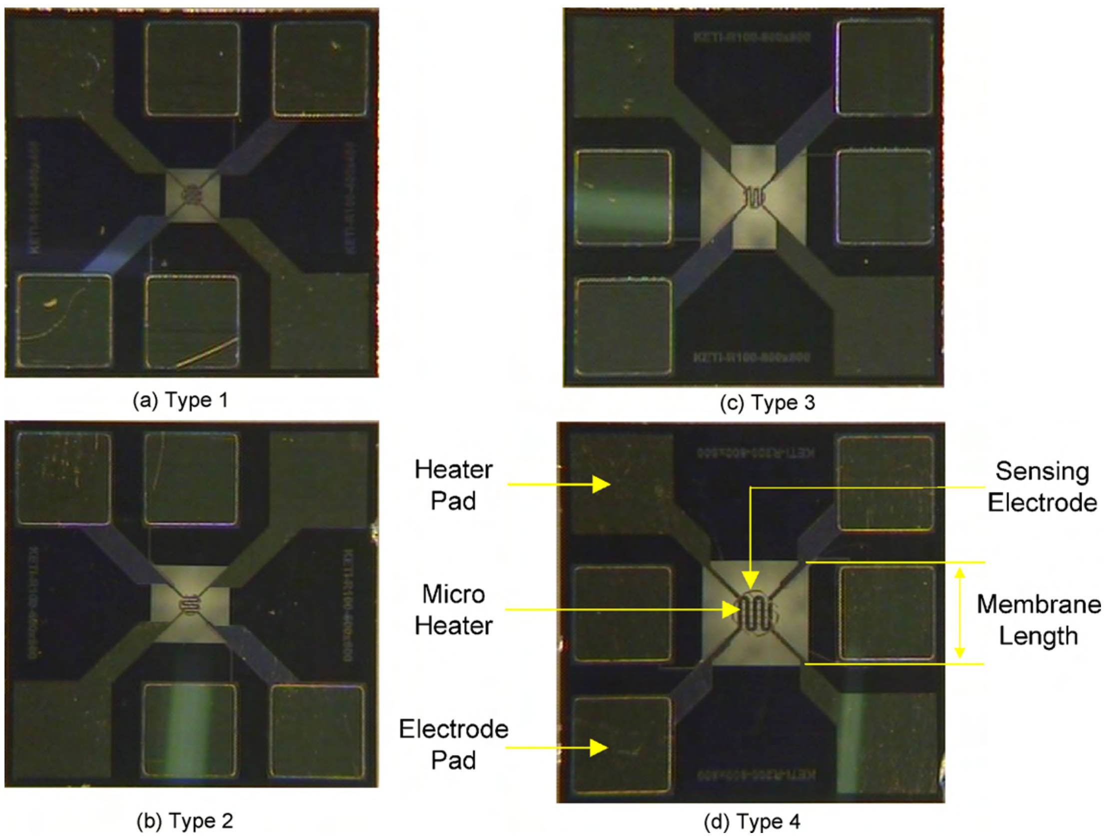

Fig. 1. Fabricated four kinds of micro-platforms: (a) type 1, (b) type 2, (c) type 3, and (d) type 4.

The heater layer of Pt on Ta was etched using a dry etching process with advanced oxide etching (AOE) equipment. An insulating layer of $SiO_2/SiN_x/SiO_2$ with a thickness of 1 μm was deposited on the patterned heater layer. A sensing electrode layer of Cr/Au film was deposited using a sputtering process, and was then patterned using a dry etching process. After finishing the front side process of the wafer, the SiN_x membrane for the low power consumption gas sensor was created on the back side of the wafer using a dry etching process, and then the patterned Si wafer was etched in a KOH solution. Finally, four types of micro-gas sensors were designed and fabricated as shown in Fig. 1, and showed the configuration of fabricated gas sensor in Fig. 1(d). A chip size is 3050 μm × 3050 μm. A type 3 micro-platform was mounted using the TO-30 package, and an enlarged image of the type 4 sensor showing the sensing electrode, micro-heater, membrane area, and heater area is provided in Fig. 2. Related information is given in our previous papers [12,13]. To measure the temperature characteristics as a function of input power for the micro-platforms using the IR-308 thermometer (Konica Minolta Co. Ltd.), the same voltage interval of 0.1 V was supplied using the power source to increase the temperature from 300 °C to 400 °C. From these results, we could calculate the power consumption as a function of temperature using the linear fit method for temperatures lower than 300 °C.

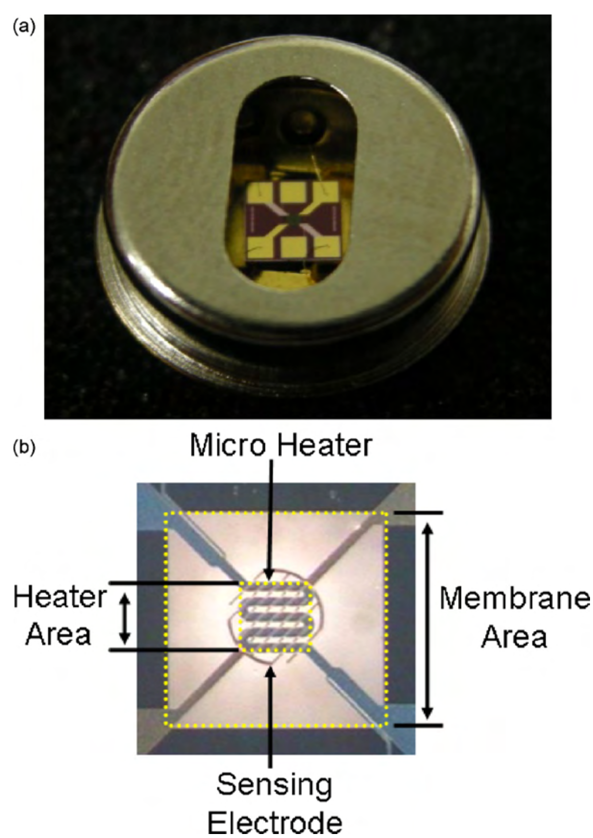

Fig. 2. (a) A type 3 micro-platform mounted on TO-30 package. (b) Configuration of membrane area, heater area, micro-heater and sensing electrode in a type 4 micro-platform image: membrane area is 1508 μm × 1508 μm.

2.2. *Sensing materials for detecting toxic gases*

SnO_2 nanoparticles with wide diameters ranging from several tens of nanometers to several hundred nanometers and the MWCNTs were mixed using polymer vehicles to make pastes for the sensing materials. The mixture was dried at 120 °C for 2 min on a hot plate in air. The process was repeated three times. The sensing material was heated with an input voltage of 2.15 V to the micro-heater for 5 min at 350 °C in air [13]. With an input voltage of 2.15 V,