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FABRICATION AND CHARACTERIZATION OF OXYGEN SENSING PROPERTIES OF DY123 SENSOR UTILIZING HOT SPOT PHENOMENON

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Abstract Characterization of oxygen sensing properties of $DyBa_2Cu_3O_{7-\delta}$ (Dy123) sensor utilizing hot spot phenomenon has been conducted. The minimum electric field for the hot spot appearance is 1.5 V/cm. After the hot spot appearance, the output current strongly depended on oxygen partial pressure (PO_2) at any selected voltage. The sensor showed very good stability and reproducibility of output current with the response time of about 5 s. The changing rate of output current increases when PO_2 decreases, with a maximum average value of 0.039 A/kPa at PO_2 between 2.5-5 kPa. The sensor is suggested as a potential candidate for low-level oxygen detection.

KEYWORDS: Oxygen sensor, Dy123, hot spot

Introduction

Worldwide, the use of oxygen sensors in automotive exhaust emission control systems currently dominates the applications of solid-state gas sensors. Among them, zirconia oxygen sensor has been the most widely used. The zirconia sensor needs to be heated above 350°C by a separate heater to operate because the electrolyte cannot work well below 350°C (Riegel *et al.*, 2002). A novel and simple type of oxygen sensor based on RE123 (RE = Gd, Sm) ceramics exploiting hot spot phenomenon was discovered by Takata *et al.*, (1999). The sensor is heater free and the oxygen sensing response performance was comparable to the widely used zirconia sensors which uses an external heater. The hot spot phenomenon that a local area of a RE123 ceramic rod glows orange with temperature of about 900°C once a voltage exceeding a certain value is applied to the rod at room temperature was observed by Okamoto *et al.*, (1994). RE123, which is well known as high-T_c superconductor material, is a typical non-stoichiometric oxide. Oxygen deficiency, δ, increases with increasing temperature above 400°C (Kishio *et al.*, 1987). The carrier density decreases with increasing δ, which results in a steep increase of the resistivity (Fiory *et al.*, 1987) and shows a positive temperature coefficient of resistivity (PTCR) characteristic. The hot spot appearance is related to the PTCR characteristic and the effect of oxygen nonstoichiometry in RE123 is identified as the underlying factor causing oxygen response (Takata *et al.*, 1999). Although some extensive works have been done on Gd123 and Sm123 (Takata *et al.*, 1999; Ibaraki *et al.*, 2001; Okamoto *et al.*, 2004), oxygen-sensing properties of other RE123 materials have not been similarly studied. In this paper, bulk sample synthesis, sensor fabrication and oxygen sensing properties of Dy123 materials are reported.

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Material and Methods

Dy123 bulk sample was prepared by the conventional solid-state reaction method. Powder X-ray Diffraction (XRD) analysis by Cu-K_α radiation using Rigaku model D/MAX 2000 PC was used to confirm the sample structure. The sample microstructure was observed by JEOL model JSM-6360LA scanning electron microscope (SEM). Dy123 sensor was fabricated by cutting the sample into rectangular rod with a fix dimension of 12 mm × 0.6 mm × 0.6 mm. The two ends of the sensor were connected to electrodes, which were separated by 10 mm using silver conductive paste. The PTCR characteristic was confirmed by heating in a box furnace from 30°C to 900°C. The hot spot appearance was tested in the open air and Fig. 1 shows the photograph of the hot spot after applying dc voltage of 1.9 V. I-V characterizations of the sensor were conducted in a chamber with flow rate and partial pressure of oxygen and nitrogen gases under control. The output current dependence after the hot spot appearance with PO_2 was investigated at a selected voltage and gas flow rate. The experimental details of sample preparation and instrumentation have been described elsewhere (Hassan *et al.*, 2006).

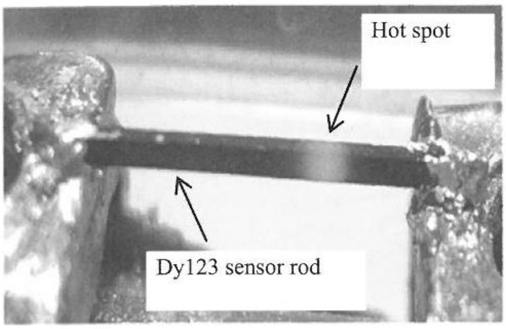

Figure 1. Photograph of hot spot after applying dc voltage of 1.9 V in open air

Results and Discussion

Figure 2 (a) shows XRD pattern of the sample and (b) shows SEM image of the internal section the sample. The XRD pattern indicates that the sample consists of single phased 123 orthorhombic structures with space group Pmmm. SEM image shows irregular shaped grains with some level of porosity.

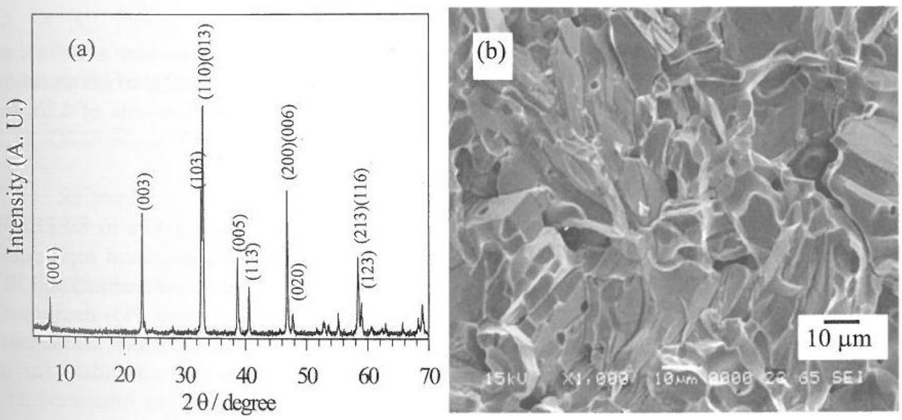

Figure 2. (a) XRD pattern of the sample and (b) SEM image of the internal section of the sample

Figure 3 (a) shows I-V characteristics of the sensor at different PO_2. The current increased with increasing voltage to a maximum value, and decreased gradually after the hot spot appearance. The voltage at which the current abruptly decreased was almost the same for all PO_2. The result shows that the minimum electric field required for the hot spot to appear is 1.5 V/cm and this is comparable to previous reports on Gd123 (Takata *et al.*, 1999) and Sm123 (Ibaraki *et al.*, 2001). The calculated peak current density for Dy123 is in general higher than that of Gd123 (Takata *et al.*, 1999) and Sm123 (Ibaraki *et al.*, 2001). For example at maximum (100 kPa) PO_2, the peak current densities for Dy123, Gd123 and Sm123 are 300 A/cm^2, 110 A/cm^2 and 180 A/cm^2, respectively.

As such Dy123 gives higher output current response and this may be an advantage compared to the other materials. After the hot spot appearance, the current strongly depended on PO_2 at any selected voltage. Based on previous works (Takata *et al.*, 1999; Ibaraki *et al.*, 2001; Okamoto *et al.*, 2004), we predict that a constant current plateau will be formed if the voltage is pushed to higher values. However, based on our experience, the rod breaks into two at around 2.5 V due to melting. To avoid breakage, the voltage was not pushed to the maximum. Figure 3 (b) shows the sensing characteristics between two different PO_2, alternately. The response time for Dy123 sensor in this work was about 5 s and is comparable to Sm123 (Takata *et al.*, 1999) and Gd123 (Okamoto *et al.*, 2004). The sensor also shows very good stability and reproducibility of output current.

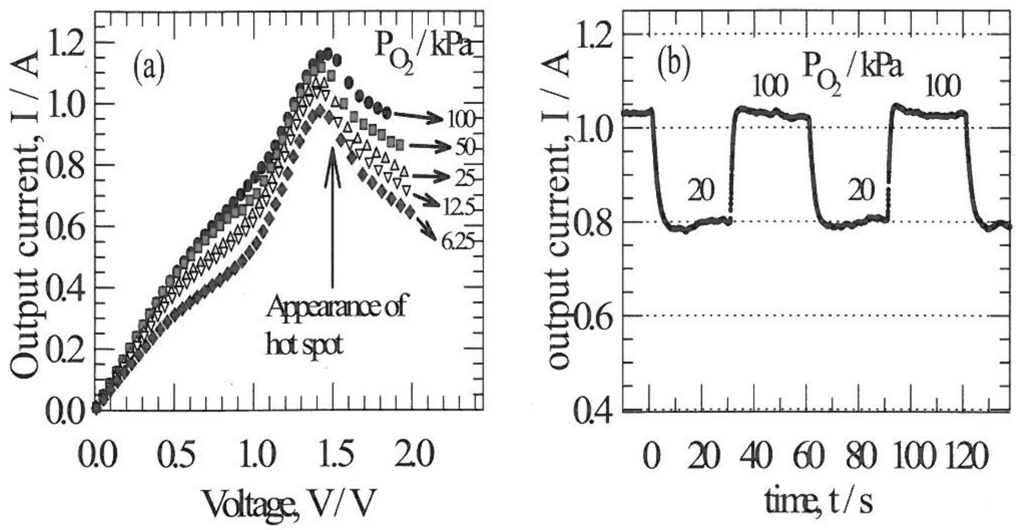

Figure 3. (a) I-V characteristics of the sensor at different PO_2. The total pressure and flow rate were fixed to 100 kPa and 4 l/min, respectively. The voltage was increased with steps of about 0.05 V every 10 s; (b) Sensing characteristics between 20 kPa (static air) and 100 kPa (flow rate of 4 l/min) of PO_2 at 1.7 V, alternately

Figure 4 (a) shows the sensing characteristics of the sensor from 2.5 kPa to 80 kPa PO_2 with different flow rate and voltage compare to Fig. 3 (b). The figure shows excellent reproducibility of output current at different PO_2. Figure 4 (b) shows the relation between output current and PO_2 of the sensor. From the figure, the changing rate of output current increases when PO_2 decreases, with a maximum average value of 0.039 A/kPa at PO_2 between 2.5-5 kPa. This shows that, the sensor is more sensitive at low-level PO_2. As such, the sensor is suggested as a potential candidate for low-level oxygen detection.

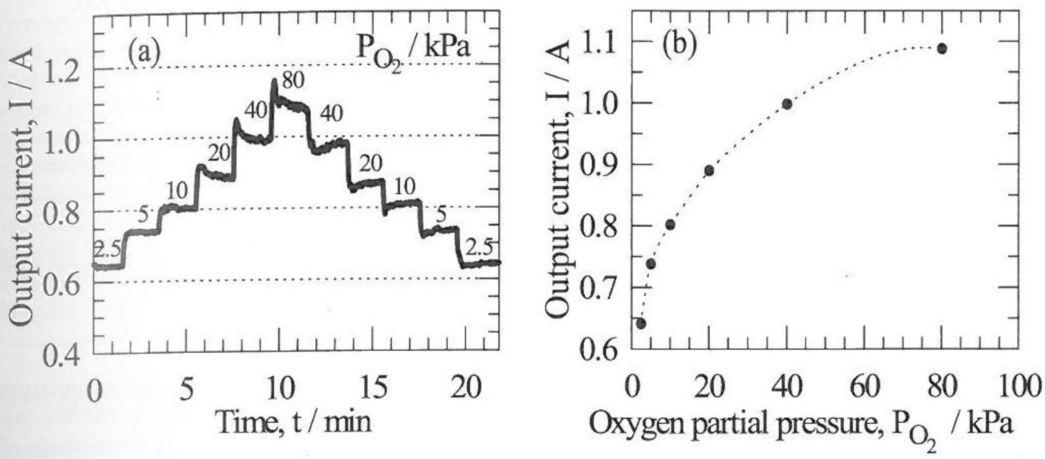

Figure 4. (a) Sensing characteristics of the sensor from 2.5 kPa to 80 kPa PO_2 at total pressure, flow rate and voltage of 100 kPa, 10 l/min and 1.9 V, respectively, and (b) Output current of the sensor as a function of PO_2. The data were derived from (a). The dotted line is as a guide to the eye only

Conclusion

Dy123 oxygen sensor has been successfully synthesized and fabricated. The performance of the sensing properties utilizing hot spot phenomenon has been characterized. The minimum electric field for the hot spot appearance is 1.5 V/cm with a peak current density of 300 A/cm^2. After the hot spot appearance, the output current strongly depended on PO_2 at any selected voltage. The sensor showed very good stability and reproducibility of output current with the response time of about 5 s. The changing rate of output current was increases when PO_2 decreases, with a maximum average value of 0.039 A/kPa at PO_2 between 2.5-5 kPa.

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