Research Report

Piezoresistive Ceramic Composite for the Miniature Force-Sensor

Hiroaki Makino, Mitsuru Asai, Shin Tajima, Nobuo Kamiya

小型・高荷重センサ用ピエゾ抵抗セラミック複合材料

牧野浩明，浅井満，田島伸，神谷信雄

Abstract

A conventional force sensor consists of a beam or a diaphragm to which a thin-metal film strain gauge or a semiconductor strain gauge is attached. The force is detected by the resistivity change in the strain gauge in accordance with the applied force. The phenomenon whereby resistivity varies with the applied force is called piezoresistivity. The necessity of attaching the gauges to the beam or the diaphragm limits the reduction in size and cost of the conventional force sensor. A material having both structural strength and the function to detect force, such as piezoresistivity, would render the beam or diaphragm unnecessary, and hence the sensor could be miniaturized and the cost would be reduced.

Therefore, the authors have developed a novel ceramic composite which has both the force detection function and structural strength by distributing an oxide material having piezoresistivity in a high-strength ceramic. As this composite enables the structural member itself to become a sensor, the size of the sensor can be markedly reduced. The authors expect that this sensor material will enable new potential applications in force detection.

Keywords　Ceramic composite, Piezoresistivity, Force sensor, Strength, Structural component

要　旨

従来の荷重センサは，金属薄膜抵抗体もしくはSi半導体の歪ゲージを起歪部に接着し，歪の大きさに応じて歪ゲージの抵抗が変化する現象ーピエゾ抵抗効果ーを利用して荷重を検出する。起歪部を必要とするため小型化に限界があった。もし構造部材そのものに歪検知機能があれば，起歪部を設けることも，ゲージを接着する必要もなくなる。したがって荷重センサを大幅に小型化・低コスト化できる。

我々は，ピエゾ抵抗効果を有する酸化物材料を高強度セラミック材料に分散複合化することにより，構造部材として使用できる強度を有する荷重センサ材料を創製した。すなわち，構造部材そのものをセンサとすることができる。新たな荷重センサ用途を切り開くことができるセンサ材料と期待している。

キーワード　セラミック複合材料，ピエゾ抵抗効果，荷重センサ，強度，構造部品

1. Introduction

The force sensor consists of a beam or a diaphragm to which a thin-metal film strain gauge or a semiconductor strain gauge is attached has been invented and used several ten years. Although it is widely applied for precise measurement, there is almost no application under severe environment such like a car. This reason is because the low reliability of gauge adhesion under severe environment and large sensor body. A material having both structural strength and the capacity to detect force, such as piezoresistivity, would render not only gauge adhersion but also beam or diaphragm unnecessary, and hence the sensor could become highly reliable, miniature and the cost would be reduced.

The purpose of the present study is to create a material which has both structural strength and piezoresistivity. In order to achieve the purpose, we have investigated the ceramic/ceramic composite which consists of high-strength ceramic and piezoresistive ceramic.

2. Experimental procedure

As the matrix, 12mol% Ce-doped partially-stabilized zirconia was chosen because among structural ceramics this material has high strength and toughness. $La_{1-X}Sr_XMnO_3$ was selected as the dispersed material in the matrix, because this material exhibits piezoresistivity near room temperature[1,2] and has adequate chemical compatibility with zirconia.[3] In the present study, the amount of strontium substitution x in $La_{1-X}Sr_XMnO_3$ was 0.2, because the piezoresistivity is relatively high at this compositon.[2]

Ceramic composites were produced via the conventional process, as shown in **Fig. 1**. A green body was fired in oxygen flow. The fired body was then machined into a rectangular specimen (5 × 5 × 1.5 mm), and then silver paste was printed on both sides of the specimen surfaces (5 × 1.5 mm).

Figure 2 shows the experimental procedure used to measure the piezoresistivity. The specimen was compressed uniaxially while measuring the resistivity.

Three-point flexural strengths were also measured.

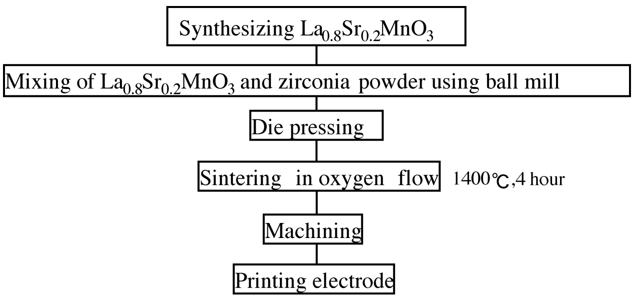

Fig. 1 Process to fabricate piezoresistive composite.

3. Result and discussion

3. 1 Material properties

The XRD chart of the composite and a back

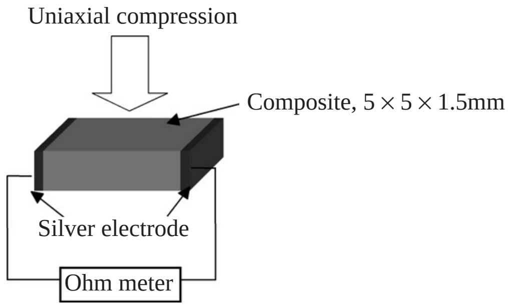

Fig. 2 Schematic figure of measuring piezoresistivity.

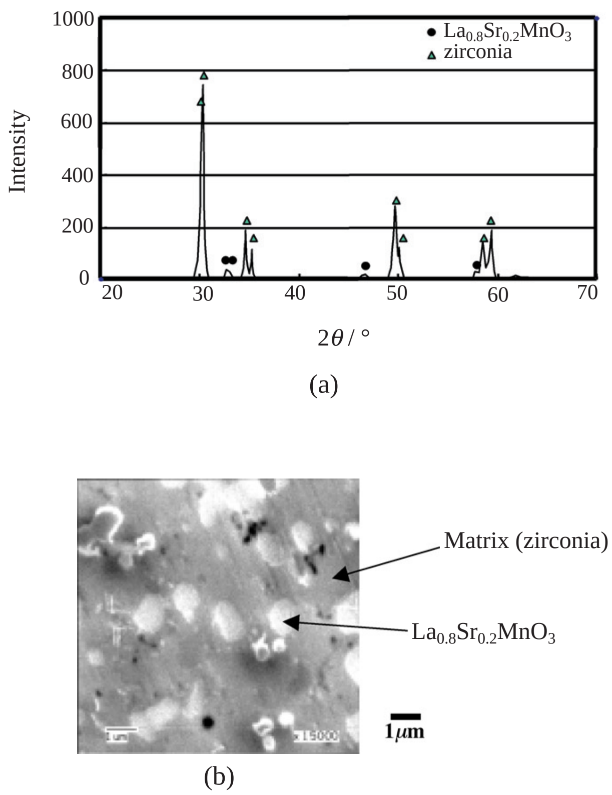

Fig. 3 XRD chart of composite (a) and back scattering electron micrograph (b) of 30% $La_{0.8}Sr_{0.2}MnO_3$ fraction.

scattering electron micrograph are shown in **Fig. 3**. Only $La_{0.8}Sr_{0.2}MnO_3$ and Zirconia were identified from the XRD chart. That is, a third phase was not synthesized during the process, within the deflection limit of the XRD.

The density of the composites is shown in **Fig. 4**. The density of the composites became more than 98% of the calculated value from the density of monolithic zirconia and $La_{0.8}Sr_{0.2}MnO_3$.

The three-point flexural strengths of the composites are shown in **Fig. 5**. The strengths of the composites were approximately 400 to 500 MPa. Although the strengths of the composites were lower than that of the matrix material (zirconia), the strengths of the composites were approximately four times higher than the strength of monolithic $La_{0.8}Sr_{0.2}MnO_3$. The strengths of the composites were considered to be sufficient for use as a structural component.

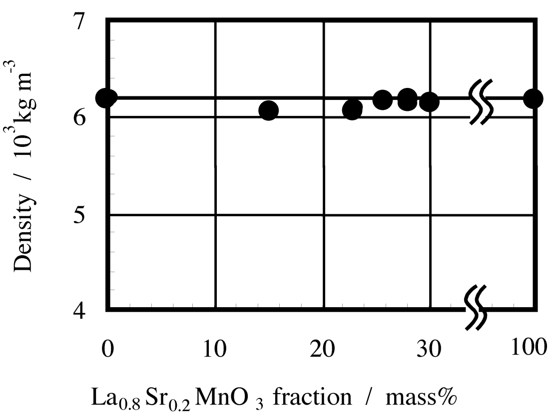

Fig. 4 Density of composite versus $La_{0.8}Sr_{0.2}MnO_3$ fraction.

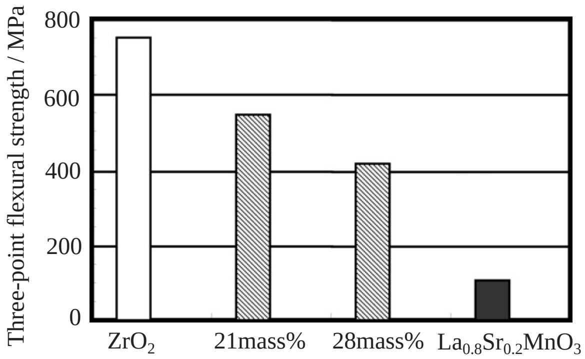

Fig. 5 Three-point flexural strength of composite.

3. 2 Electrical properties

The relationship between $La_{0.8}Sr_{0.2}MnO_3$ volume fraction and the resistivity of composite is shown in **Fig. 6**. Percolation conduction occurred at a fraction of over 18%, and the resistivity became small as the fraction increased. One of the advantages of composite materials is that the resistivity can be controlled using the fraction in accordance with the sensor design.

A resistivity change of 30mass% composite and monolithic $La_{0.8}Sr_{0.2}MnO_3$ under compressive stress is shown in **Fig. 7**. The slope of the graph, i.e., the piezoresistivity of the composite was slightly less than that of $La_{0.8}Sr_{0.2}MnO_3$, as expected, but the magnitude and of the linearity of the slope seemed to be sufficient for use as a force sensor.

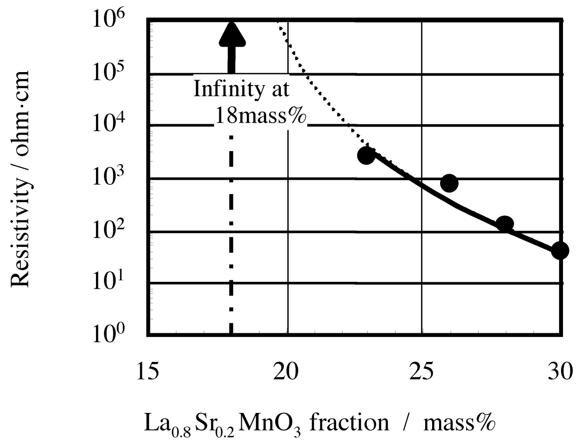

Fig. 6 Relationship between $La_{0.8}Sr_{0.2}MnO_3$ fraction and resistivity of composite.

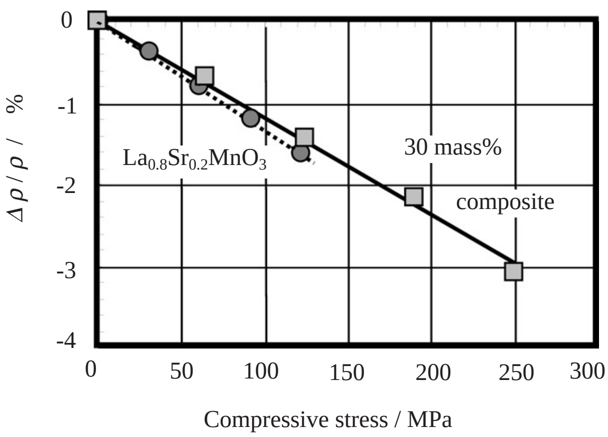

Fig. 7 Resistivity change of 30mass% composite and $La_{0.8}Sr_{0.2}MnO_3$ under compressive stress.

The relationship between $La_{0.8}Sr_{0.2}MnO_3$ fraction and the piezoresistivity coefficient π_{12} is shown in **Fig. 8**. Piezoresistivity increased slightly with increasing fraction. This is considered to occur because the Young's modulus decreases with the fraction, as shown in **Fig. 9**, and as a result the strain is increased.

The resistivity and the piezoresistivity coefficient of the composite exhibited a specific temperature dependence, which will be discussed in a future paper. Application of the new material to a wide range of industrial applications requires improvement of the temperature dependence.

4. Summary

A force sensor material having both a force sensing function and structural strength has been developed for the first time. This new material enables the structural member itself to become a sensor, and so the size of the sensor can be reduced remarkably. The new sensor material is expected to enable new potential applications in force detection.

References

1) Moritomo, Y., Asamitsu, A. and Tokura, Y. : "Pressure Effect on the Double-exchange Ferromagnet $La_{1-X}Sr_XMnO_3$(0.15≦X≦0.5)," Phys. Rev. B, **51**-22(1995), 16491
2) Zhang, N., Ding, W. P., Guo, Z. B., Zhong, W., Xing, D. Y., Du, Y. W., Li, G. and Zheng, Y. : "Large Lattice Compression Coefficient and Uniaxial Piezoresistance in CMR Perovskite La1-XSrXMnO$_3$ (0.15≦X≦0.25)," Zeitschrift fur Physik B, **102**(1997), 461
3) Takeda, Y., Sakaki, T., Tu, H. Y., Phillips, M. B., Imanishi, N. and Yamamoto, O. : "Perovskite Oxides for the Cathode in Solid Oxide Fuel Cells," Electrochemistry, **68**-10(2000), 764

(Report received on Sep. 2, 2002)

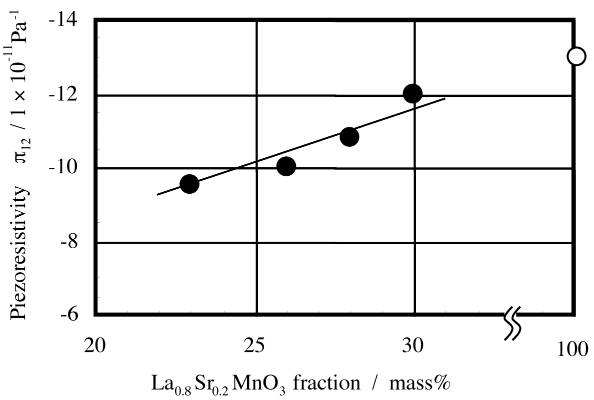

Fig. 8 Relationship between $La_{0.8}Sr_{0.2}MnO_3$ fraction and piezoresistivity coefficient π_{12}.

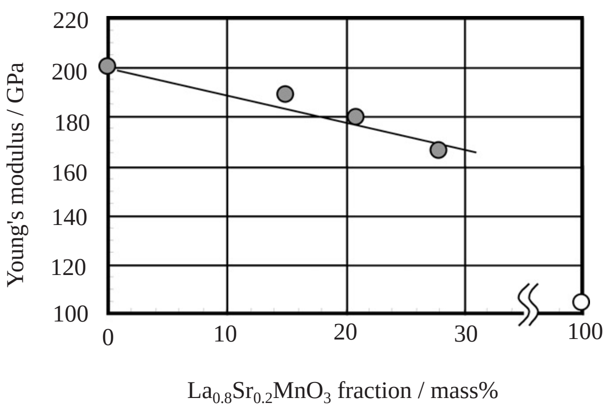

Fig. 9 Relationship between $La_{0.8}Sr_{0.2}MnO_3$ fraction and Young's modulus.

Hiroaki Makino 牧野浩明
Year of birth : 1960
Division : Inorganic Mater. Lab.
Research fields : Inorganic material
Academic society : Ceram. Soc. of Jpn., Am. Ceram. Soc.

Mitsuru Asai 浅井 満
Year of birth : 1954
Division : Inorganic Mater. Lab.
Research fields : Inorganic material
Academic society : Ceram. Soc. of Jpn.

Shin Tajima 田島 伸
Year of birth : 1963
Division : Metallic. Mater. Lab
Research fields : Inorganic material, Magnetic material
Academic degree : Dr. Eng.
Academic society : Ceram. Soc. of Jpn., Mag. Soc. of Jpn., Jpn. Soc. of. Pow. and Pow. Metal.

Nobuo Kamiya 神谷信雄
Year of birth : 1948
Division : Organic Mater. Lab.
Research fields : Inorganic material
Academic degree : Dr. Eng.
Academic society : Ceram. Soc. of Jpn., Am. Ceram. Soc. Jpn., Soc. of Appl. Phys.