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# Characteristics of Flow Sensor Using PTC Thermistor

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# PTC 써어미스터를 이용한 유속센서의 특성

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## Abstract

Flow sensor was fabricated with PTC thermistor usually operating as thermostats. The PTC thermistor was manufactured with $(Ba_{0.7}Sr_{0.3})TiO_3$ powder and its resistivity as a function of flow velocity was investigated. The resistivity changed from 4.45 kΩ·cm to 3.95 kΩ·cm as flow velocity varied 0 cm/s to 5 cm/s The sensitivities of the PTC thermistor were -204 (Ω·cm)/(cm/s) and -24 (Ω·cm)/(cm/s) at the flow velocity of 1 cm/s and 5 cm/s, respectively.

## 요 약

정온발열 특성을 갖는 PTC 써어미스터를 사용하여 유속센서를 제조하였다. $(Ba_{0.7}Sr_{0.3})TiO_3$ 분말을 사용하여 PTC 써어미스터를 제조한 후, 유속에 따른 저항률의 변화를 조사하였다. 유속이 0 cm/s에서 5 cm/s로 변할 경우 저항률은 4.45 kΩ·cm에서 3.95 kΩ·cm로 변하였다. 유속이 1 cm/s와 5 cm/s일 경우 PTC 써어미스터의 감도는 -204 (Ω·cm)/(cm/s)와 -24 (Ω·cm)/(cm/s)로 나타났다.


## I Introduction

Many researches have been carried out on a universal flow sensor that could measure flow velocity with high accuracy over wide ranges.[1] There are many different types of flow sensors on the market. However, most commonly used flow sensors are expensive and their manufacturing processes are quite complicated. A great effort has been given on the less expensive flow sensors which operate accurately. We fabricated flow sensor with PTC (Positive Temperature Coefficient) thermistor and its characteristics were investigated on this paper. PTC thermistor is very useful for the thermostat, self-heat, and current density-limit devices.[2-5] The thermistor operating as a thermostat can be used for flow sensor because the thermistor is sensitive to the power dissipation caused by the flowing fluid. The power dissipation varries with flow velocity when the thermistor is placed in the flowing fluid. PTC thermistor is manufactured with $BaTiO_3$ and some additives.[6-8] The resistivity of fabricated thermistor increases abruptly about 120℃, which temperature is too high to operate as a flow sensor. $(Ba_xSr_{1-x})TiO_3$ PTC thermistor can be achieved by substituting Ba in $BaTiO_3$ for Sr and its curie temperature moves to lower temperature, which is suitable for a flow sensor, when it contains more Sr.[7,8] The PTC thermistor is very sensitive to the flow velocity and temperature. The resistivity of the PTC thermistor must depend on the flow velocity and is independent of the temperature of the fluids. PTC thermistor, thus, has to compensate the temperature of the

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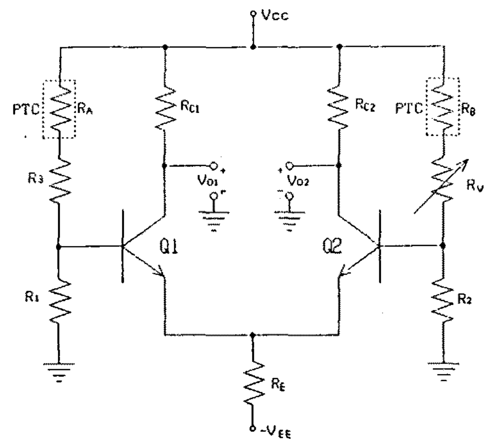
fluids. The reference PTC thermistor is used for temperature compensation of the fluid. Differential amplifier circuit is used for the flow sensor and temperature compensation. The voltage difference between the flow-sensing thermistor and the reference thermistor is applied to the input of the differential amplifier, which is amplified to measure the output voltage of the circuit. The elements of the circuit can be changed for the flow sensor operating at different flow ranges.

## II Experimental procedure and measurements

As-received $(Ba_{0.7}Sr_{0.3})TiO_3$ powder is used to manufacture the PTC thermistor. The powder is pressed at 1 ton/cm$^2$ for 60 seconds and sintered at 1340℃ for 2 hours. The temperature increase and temperature decrease are at a rate of 200℃/h and 100℃/h, respectively. Al is evaporated on the both sides of PTC thermistor for the electrode, which is annealed at 400℃ for 1 hour. The circuit for the flow sensor using PTC thermistors is shown in Fig. 1.




$V_{cc}$=12V, $R_{c1}$=$R_{c2}$=3.3kΩ, $R_E$=5.6kΩ, $R_1$=$R_2$=20Ω, $R_3$=100Ω

Fig. 1. Circuit for flow sensor using PTC thermistors.

Thermistors A and B are used for the measurement of flow velocity and for the temperature compensation, respectively. The resistivity of the PTC thermistor increases with time when the voltage is applied to the circuit at t = 0 s, which is leveled off with further increase in time due to self-heating characteristics. There is no voltage difference between $Vo_1$ and $Vo_2$ if the thermistors A and B are identical, which is very difficult to manufacture. Therefore, the resistances $R_v$ and $R_3$ are necessary to get the output voltage difference zero. The fluid is nitrogen and flow velocity is calculated measuring the quantity of the flowing gas by flow meter(UESHIMA Co., R-2-15-D, glass). Fig. 2 shows a system incorporating two PTC thermistors. PTC A is to measure the flow velocity and PTC B is to compensate the temperature of the fluid(nitrogen). The output voltage in Fig. 1 is zero when the nitrogen does not flow, even if the temperature of nitrogen varies. The resistivity of the PTC thermistor B remains unchanged, while the resistivity of the PTC thermistor A becomes lower because of energy dissipation when the flow changes.

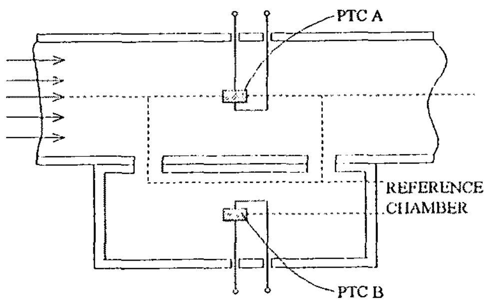



Fig. 2. Set-up of a flow sensor using the PTC thermistors.

Fig. 3 shows the operating points of the two PTC thermistors. The power dissipated by gas flow can be expressed by

$$P = k_1(T_N - T_U) \quad (1)$$

where P is the power dissipation by gas flow, $k_1$ is a proportional constant, $T_N$ is the temperature of PTC thermistor when gas flows, and $T_U$ is the temperature of PTC thermistor when no gas flows. The power dissipation determines the temperature of the PTC thermistor, and correspondingly its resistivity. The change in resistivity, therefore, becomes a function of flow velocity. Eq. 1 can be expressed as

$$P = aT_N + b \quad (2)$$

where a and b are constants. Power dissipation is linearly proportional to the temperature of the flow-sensing PTC thermistor. When there is power dissipation, power has to be supplied to the thermistor because the thermistor operates as a thermostat.

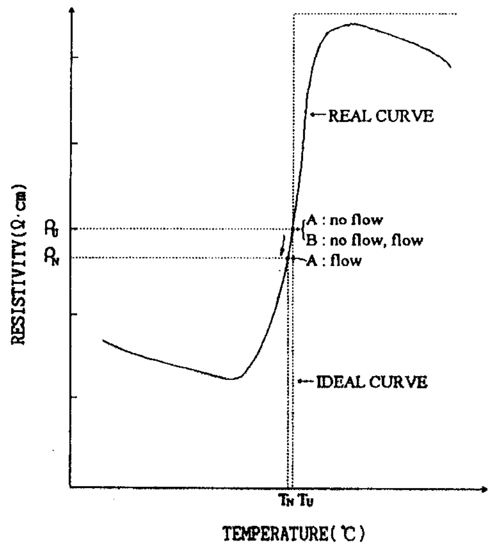



Fig. 3. Operating point of the PTC thermistor with or without gas flow.

## III Results and Discussion

$(Ba_{0.7}Sr_{0.3})TiO_3$ is sintered at 1340℃ for 2 hours and the resistivity-temperature(ρ-T) characteristics of the PTC thermistor is shown in Fig. 4. The resistivity abruptly increases nearby 60℃. The resistivity at room temperature, the maximum resistivity, and the resistivity jump (the ratio of room temperature resistivity and maximum resistivity) are measured with 230 Ω·cm, $1.2\times10^7$ Ω·cm, and $5.2\times10^4$, respectively.

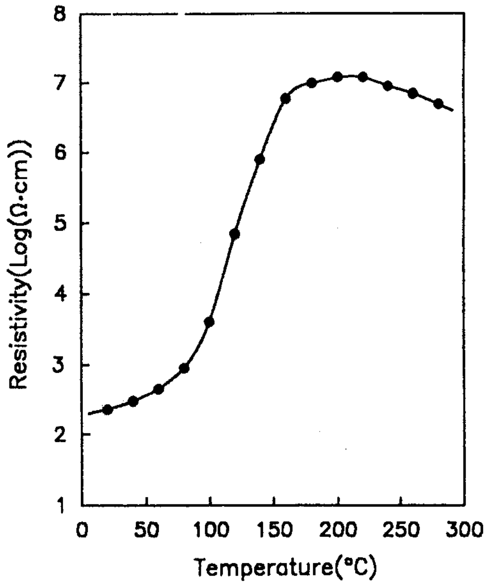



Fig. 4. Resistivity versus temperature characteristics of $(Ba_{0.7}Sr_{0.3})TiO_3$ PTC thermistor sintered at 1340℃ for 2 hours.

Fig. 5 shows the current density-time (J-t) characteristics of the thermistor when gas does not flow. Electric field is applied at t = 0 to measure the current density. The current density decreases with time. Current densities at t = 0 are 113 mA/cm$^2$, 192 mA/cm$^2$, 304 mA/cm$^2$, and 374 mA/cm$^2$, whereas the current densities at t = 25 seconds are 25.6 mA/cm2, 23.4 mA/cm$^2$, 21.1 mA/cm$^2$, and 19.6 mA/cm$^2$, when the applied electric fields are 50 V/cm, 100 V/cm, 150 V/cm, and 200 V/cm, respectively. The static current density-electric field(J-E) curve of the thermistor is distinguished by the maximum current density (at t = 0) followed by the nearly constant limiting-current density region as the time increases. The current density does not change after 25 seconds, which indicates that the thermistor is in equilibrium condition and operates as a thermostat. The higher the electric field, the lower the current density, because constant power is supplied to the thermistor to operate as a thermostat.

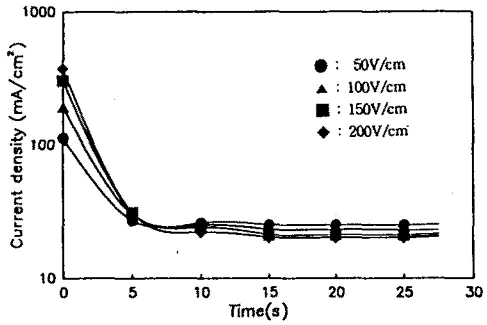



Fig. 5. Current density versus time characteristics of PTC thermistor sintered at 1340℃ for 2 hours.

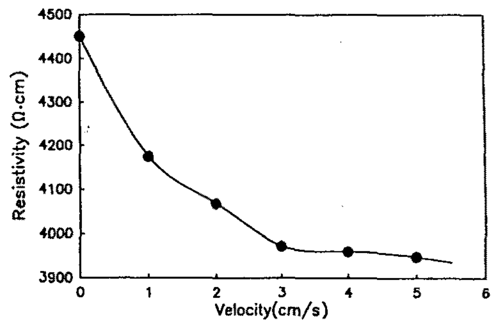



Fig. 7. Resistivity versus nitrogen's flow velocity for the flow sensor.

Fig. 6 shows the static current density-electric field(J-E) characteristics in equilibrium. We assume that the thermistor operates in equilibrium after 60 seconds because the current density is not changed after 25 seconds. The joule heating increases the thermistor temperature, which enhances the resistivity and hence decreases the current density.

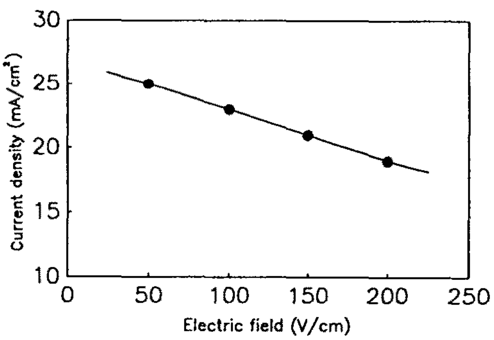



Fig. 6. Current density versus electric field characteristics of PTC thermistor sintered at 1340℃ for 2 hours.

The thermistor's resistivity as a function of the flow velocity is shown in Fig. 7. The resistivity decreases with increasing the flow velocity. The resistivities are 4.45 kΩ·cm, 4.18 kΩ·cm, 4.07 kΩ·cm, 3.97 kΩ·cm, 3.96 kΩ·cm, and 3.95 kΩ·cm at the flow velocities of 0 cm/sec, 1 cm/s, 2 cm/s, 3 cm/s, 4 cm/s, and 5 cm/s, respectively.

The sensitivity of the PTC thermistor shown in Fig. 8 is influenced by the flow velocity. The sensitivity is defined by

$$S = \frac{\Delta \rho}{\Delta v} \qquad (3)$$

where S is the sensitivity of the PTC thermistor, ρ is the resistivity of the PTC thermistor, and v is the nitrogen flow velocity.

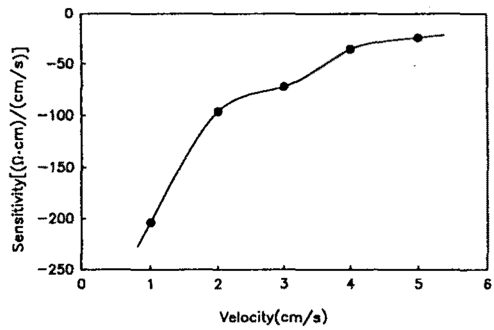



Fig. 8. Sensitivity versus nitrogen's flow velocity for the flow sensor.

The sensitivities are -204 (Ω·cm)/(cm/s), -96 (Ω·cm)/(cm/s), -72 (Ω·cm)/(cm/s), -36 (Ω·cm)/(cm/s), and -24 (Ω·cm)/(cm/s) at the flow velocities of 1 cm/s, 2 cm/s, 3 cm/s, 4 cm/s, and 5 cm/s, respectively. The sensitivity decreases with increasing the flow velocity. The resistivity of the thermistor A in Fig. 3 becomes lower compared to that without flow. The temperature difference becomes larger when the flow velocity increases. However, the energy dissipation of the thermistor becomes saturated when the gas flows faster. The thermistor is more sensitive at lower flow velocity. Power dissipation of the thermistor as a function of flow velocity shown in Fig. 9 is calculated from the current density and resistivity of the thermistor. Power dissipation increases with increasing the flow velocity, but the increase of the power per unit velocity decreases with increasing the flow velocity. Therefore, the sensitivity of the thermistor decreases with increasing the flow velocity. The sharply ascending PTC curves are desirable for the highly sensitive flow sensors where $\triangle\rho/\triangle T$ should be as large as possible. However, measurable range of the flow velocity becomes narrower when the PTC thermistor is more sensitive to the flow velocity.

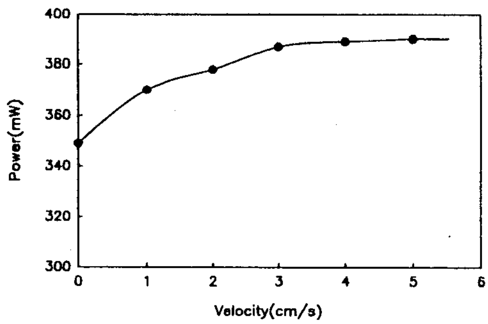



Fig. 9. Power dissipation versus nitrogen's flow velocity for the flow sensor.

The voltage gains in Fig. 1 are calculated to get $AC_M$ = -0.29, $AD_M$ = -200, and CMRR = 690. $V_{o1}$ decreases with increasing flow velocity but $V_{o2}$ increases. The voltage difference($V_{o2}$ - $V_{o1}$) increases with increasing flow velocity. Base input voltage of $Q_1$ in Fig. 1 is given by

$$V_{BB1} = \frac{R_1}{R_1 + R_3 + R_A} V_{CC} \quad (4)$$

$R_A$ decreases as flow velocity increases. Therefore, $V_{BB1}$ increases as flow velocity increases allowing $I_{C1}$ to increase. Eq. 1 shows that $V_{o1}$ decreases with increasing flow velocity. $V_{BB2}$ is a constant when gas temperature remains unchanged. Two input voltages can separate as follow

$$V_{DM} = \frac{V_{BB1} - V_{BB2}}{2} \quad (5)$$

$$V_{CM} = \frac{V_{BB1} + V_{BB2}}{2} \quad (6)$$

output voltages are

$$V_{o1} = A_{CM}V_{CM} + A_{DM}V_{DM} \quad (7)$$

$$V_{o2} = A_{CM}V_{CM} - A_{DM}V_{DM} \quad (8)$$

therefore

$$V_o = V_{o2} - V_{o1} = -2A_{DM}V_{DM} \quad (9)$$

Fig. 10 shows the relationship between flow velocity and output voltage($V_o$). When the flow velocity increases, output voltage increases and the sensitivity decreases. This flow sensor will be useful for nitrogen flow sensor. The sensing range of the flow sensor depends on resistivity-temperature(ρ-T) characteristics of PTC thermistor. It is, therefore, desirable to manufacture the controllable PTC thermistor at wide ranges of flow.

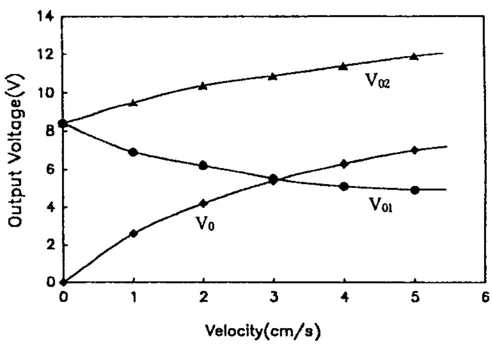



Fig. 10. Output voltage versus nitrogen's flow velocity for the flow sensor.

## Ⅳ Conclusion

We have manufactured flow sensor using PTC thermistors. The resistivity of the PTC thermistor changes 4.45 kΩ·cm to 3.95 kΩ·cm as flow velocity changes 0 cm/s to 5 cm/s The resistivity decreases with increasing flow velocity. The sensitivities of the PTC thermistor are -204 (Ω·cm)/(cm/s) and -24 (Ω·cm)/(cm/s) at the velocities of 1 cm/s and 5 cm/s, respectively. The PTC thermistor is more sensitive at low flow velocity.

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