DEVELOPMENT OF A COMBINED PSP/TSP SENSOR USING QUANTUM DOT

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ABSTRACT: Pressure-Sensitive Paint (PSP) has been utilized for non-intrusive pressure measurements on a solid surface; pressure is deduced from the luminescence intensity of PSP. Since the intensity depends not only on pressure but also on temperature, PSP result has to be compensated by the surface temperature. Temperature-Sensitive Paint (TSP), whose luminescence intensity depends only on temperature, is promising to measure the temperature of a surface. In this paper, we propose a combined PSP/TSP sensor using PtTFPP and a quantum dot (CdSe/ZnS) as PSP and TSP luminophores, respectively. Quantum dots have a large potential as TSP luminophore of the combined sensor because of its tunable luminescence peak wavelength, high quantum yield and broad absorption band. We made a combined sensor by dipping a TLC plate into a PtTFPP and CdSe/ZnS mixture cocktail, and examined its fundamental properties such as pressure and temperature sensitivities. As a result, PtTFPP has pressure sensitivity of 0.77 %/kPa near atmospheric pressure, while the quantum dot is insensitive to pressure. It is also revealed that the quantum dot has sufficient temperature sensitivity of -0.84 %/K near room temperature.

1 Introduction

A Pressure-Sensitive Paint (PSP) measurement technique has been developed for several decades [1]. PSP is a pressure sensor whose luminescence intensity varies with pressure. In general, the luminescence is also thermally quenched; thus the luminescence intensity usually decreases with a temperature rise. For a precise pressure measurement, it is important to simultaneously measure the surface temperature with the PSP measurement and to correct the effect of the temperature on the PSP result. An IR camera is often used to measure the temperature [2]; however, the method has problems such as the reflection from other heat sources and the unknown emissivity of the PSP surface. Temperature-Sensitive Paint (TSP) is a promising temperature sensor, because most of the apparatuses can be shared with the PSP measurement. In the previous study, for symmetric flow fields around a symmetric model, temperature correction was carried out by coating PSP and TSP on starboard and port side of the model under the assumption that pressure and temperature distributions were also symmetric [3]. However, this method cannot be applied to asymmetric flow fields.

We made a combined PSP/TSP sensor, mixture paint of PSP and TSP, to overcome the difficulty. The combined sensor was composed of PtTFPP and CdSe/ZnS as the PSP and TSP luminophores, respectively. CdSe/ZnS is one of quantum dots and its luminescent wavelength is tunable by varying the dot size. This paper reports pressure and temperature sensitivities of the sensor.

2 Pressure sensitivity and temperature sensitivity of PSP and TSP

PSP and TSP are composed of luminophore and binding material. When the paints are illuminated with the light of a proper wavelength, the luminophore emits the light of a longer wavelength. In PSP and TSP measurements, surface pressure and temperature are deduced from the luminescence intensity.

In PSP measurement, luminescence intensity is converted to pressure by the following Stern-Volmer equation,

$$\frac{I_{\mathrm{ref}}}{I}\left(=\frac{I\left(P_{\mathrm{ref}},T\right)}{I\left(P,T\right)}\right)=A_0\left(T\right)+A_1\left(T\right)\frac{P}{P_{\mathrm{ref}}}. \tag{1}$$

Here I, T and P are luminescence intensity, temperature and pressure, respectively. Subscript ref represents reference condition. A_0 and A_1 are so-called Stern-Volmer coefficients, which are calculated from calibration data. The coefficients are the function of temperature because the radiationless deactivation is temperature-dependent. Therefore, the pressure values calculated from PSP luminescence include the temperature effect when there is a temperature distribution on the surface.

In TSP measurement, luminescence intensity is converted to temperature by an appropriate equation which well fits experimental values. In this paper, the following equation was used.

$$\frac{I}{I_{\mathrm{ref}}}\left(=\frac{I\left(T\right)}{I\left(T_{\mathrm{ref}}\right)}\right)=B_0+B_1\frac{T}{T_{\mathrm{ref}}}, \tag{2}$$

where B_0 and B_1 are pressure-independent coefficients. As shown in Eq. (2), the TSP luminescence is independent of pressure. Therefore, TSP is able to measure the temperature distribution without any correction despite a pressure distribution on the surface.

3 Composition of combined PSP/TSP sensor

A combined PSP/TSP sensor, which includes pressure sensitive and temperature sensitive luminophores, enables us to simultaneously measure the surface pressure and temperature by separately detecting luminescences from both luminophores at the same time. Since a measurement system is favorable to be as simple as possible, it is better to excite both luminophores by a single light source, and that their luminescences do not overlap in wavelength to separate PSP luminescence from TSP one by only optical filters.

We employed PtTFPP as a pressure sensitive luminophore because of its high pressure sensitivity around atmospheric pressure. The absorption and emission spectra of PtTFPP have peaks around 395 nm and 650 nm, respectively [4, 5]. CdSe/ZnS is one of favorable candidates of the temperature sensitive luminophore due to its following notable features: tunable peak wavelength of the luminescence (from 480 nm to 640 nm), narrow full width at half maximum (narrower than 40 nm), high quantum yield (30-50 %) and broad absorbing spectrum (from UV to visible light) [6]. We chose the CdSe/ZnS whose luminescence peak wavelength is 530 nm (Lumidot 530, Sigma-Aldrich) as temperature sensitive luminophore to separate its luminescence from the PtTFPP one.

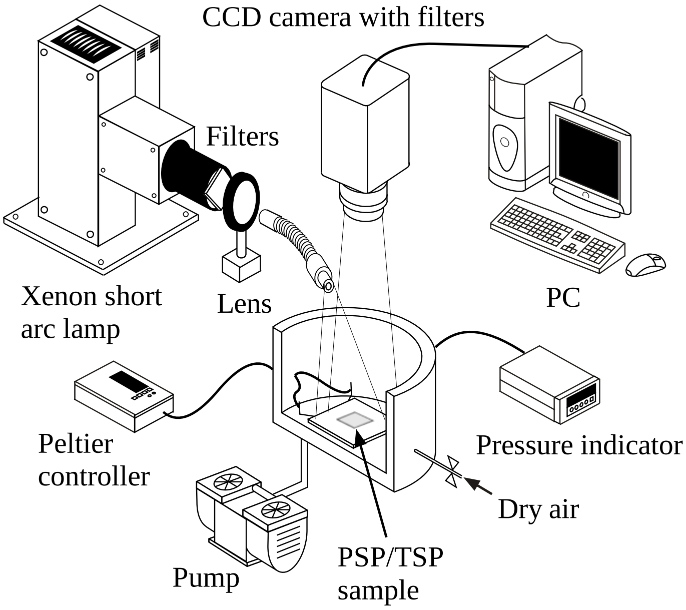


Fig. 1 Experimental apparatus

4 Sample preparation and experimental apparatus

4.1 Sample preparation

Three kinds of toluene solutions of luminophores were prepared; only PtTFPP (0.1 mg/mL), only CdSe/ZnS (0.5 mg/mL), and PtTFPP and CdSe/ZnS mixture cocktail. The cocktail was made by dissolving 0.1 mg of PtTFPP and 0.5 mg of CdSe/ZnS into 1 mL of toluene. Three kinds of sample coupons were prepared by dipping a TLC plate into these three solutions for 60 min.

4.2 Experimental apparatus and procedure

Figure 1 shows an experimental apparatus for pressure and temperature calibrations. The prepared sample coupons were set in a chamber and illuminated by the light of a xenon short arc lamp through a band-pass filter (395±5 nm). The pressure in the chamber was controlled by using a pump and dry air (O_2: 21 %, N_2: 79 %). The temperature of the sample was controlled by a Peltier device. The luminescence emitted from the sample was detected by a CCD camera (Imager Compact, LaVision). An appropriate band-pass filter was set to a camera lens to detect only the luminescence emitted from each luminophore of the combined sensor: the filter of 670±60 nm is used for detecting PtTFPP (PSP) luminescence and that of 530±60 nm is for CdSe/ZnS (TSP).

Pressure sensitivity was examined at 293 K. The chamber pressure was varied from 80 to 120 kPa every 10 kPa. Temperature sensitivity was examined at 101 kPa. The sample temperature was varied from 293 to 313 K every 5 K. In the calibrations, four images were averaged at each measuring point to reduce a random noise.

5 Results and discussions

Figure 2 shows an emission spectrum of the combined PSP/TSP sensor. As shown in this figure, luminescences emitted from PtTFPP and CdSe/ZnS of the combined sensor have no overlap between them, and were able to separate each other around the wavelength of 600 nm.

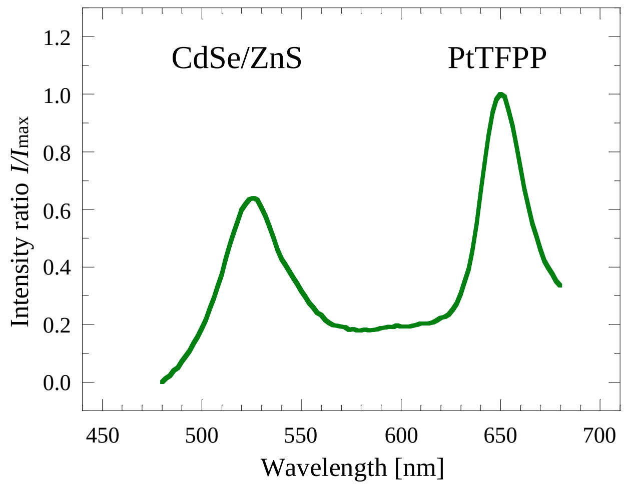
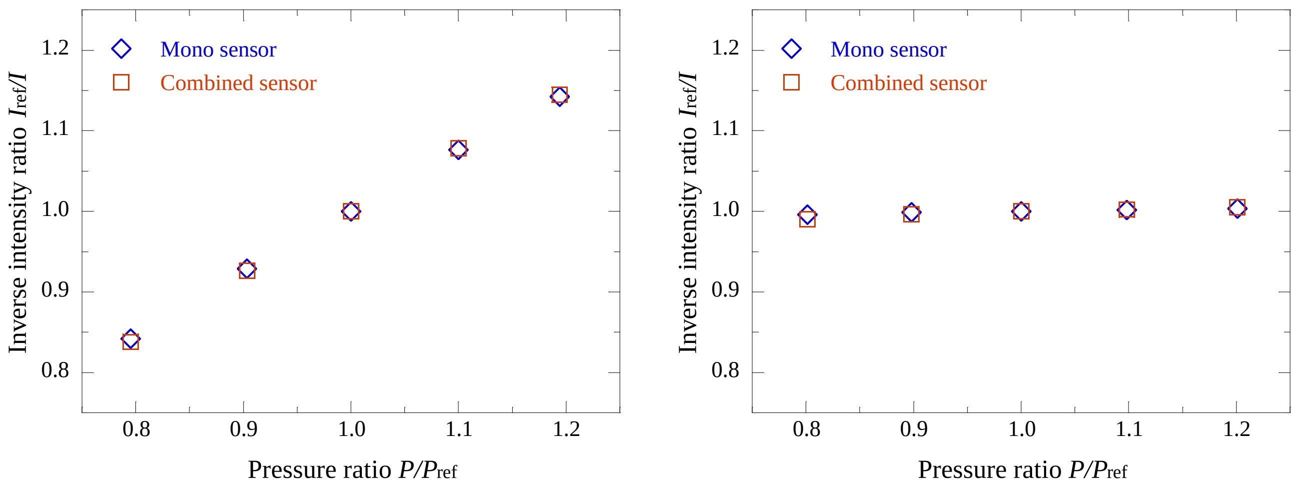
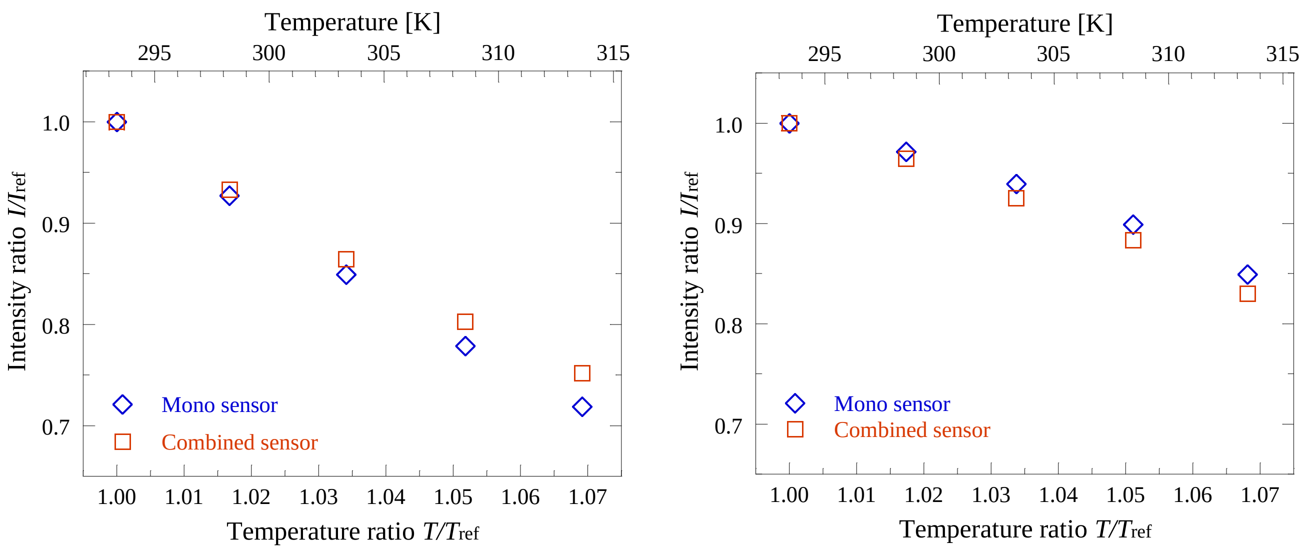


Fig. 2 Emission spectrum of the PSP/TSP combined sensor



(a) PtTFPP (PSP) (b) CdSe/ZnS (TSP)

Fig. 3 Pressure sensitivity: Stern-Volmer plot (P_{ref}=101kPa, T=293K)



(a) PtTFPP (PSP) (b) CdSe/ZnS (TSP)

Fig. 4 Temperature sensitivity (P=101kPa, T_{ref}=293K)

Pressure sensitivity of the combined PSP/TSP sensor is shown in Fig. 3: (a) PtTFPP and (b) CdSe/ZnS. For comparison, results of PtTFPP and CdSe/ZnS mono sensor are also plotted in Fig. 3(a) and 3(b), respectively. As shown in Fig. 3(a), PtTFPP of the combined sensor had a pressure sensitivity of 0.77 %/kPa, which was almost the same as PtTFPP mono sensor. On the contrary, CdSe/ZnS of the combined sensor had little sensitivity, less than 0.04 %/kPa, as shown in Fig. 3(b). These results show that PtTFPP and CdSe/ZnS are favorable candidates as PSP and TSP luminophores, respectively, from the point of view of pressure sensitivity.

Figure 4 shows temperature sensitivity of the conbined sensor: (a) PtTFPP and (b) CdSe/ZnS. Results of each mono sensor are also plotted in these figures. From Fig. 4(a), it can be seen that PtTFPP had a large temperature sensitivity of -1.23 %/K. As shown in Fig. 4(b), tempearature sensitivity of CdSe/ZnS was -0.84 %/K, which was enough high to correct the temperature error of PtTFPP, and was comparable to CdSe/ZnS mono sensor.

Conclusion

A combined PSP/TSP sensor was made by dipping a TLC plate into PtTFPP and CdSe/ZnS mixture cocktail. As a result of its pressure sensitivity and temperature sensitivity tests, the following concluding remarks are obtained;

1. PtTFPP had large pressure sensitivity of 0.77 %/kPa even in a mixture with CdSe/ZnS.
2. CdSe/ZnS had little pressure sensitivity (less than 0.04 %/kPa) and had sufficient temperature sensitivity of -0.84 %/K for the compensation of the PSP result.

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