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ISS ソーレ係数測定実験における定常状態のみを用いた干渉縞解析手法

Interference Fringes Analysis Method Using Only Steady State in ISS Soret Coefficient Measurement

小田嶋俊宏 [1], 折笠勇 [1], 富永晃司 [1], 稲富裕光 [2,3], 鈴木進補 [1]
Toshihiro ODAJIMA[1], Isamu ORIKASA[1], Kohji TOMINAGA[1], Yuko INATOMI[2,3] and Shinsuke SUZUKI[1]
[1] 早稲田大学，Waseda University.
[2] 宇宙航空研究開発機構，Japan Aerospace Exploration Agency.
[3] 総合研究大学院大学，The Graduate University for Advanced Studies, SOKENDAI.

1. Introduction

The Soret coefficient S_T, which quantitatively represents the Soret effect, was measured on the International Space Station (ISS) as Soret-Facet Mission[1)]. The value of S_T is obtained as a ratio of the resulting concentration gradient ∇C to temperature one ∇T applied to a homogenized solution through observing interference fringe changes in-situ for several hours using an interferometer. The problems of this measurement method are necessity to analyze huge observation data to obtain the spatial gradient of fringe phase $\nabla\phi(x)$ and difficulty to identify a reliable ∇C with narrow observation area due to limitations such as the thermal design. We then proposed a method to move the observation field of view after in-situ observation to obtain $\nabla\phi(x) = f(\nabla T(x),\nabla C(x))$ and convert it to ∇C referring to a reliable ∇T without analyzing huge observation data. It is easier and more preferable to refer to thermocouple data ∇T_{TC} than to in-situ observation one $\nabla T_{\mathrm{in\text{-}situ}}$, which requires several minutes of observation data analysis. However, ∇T_{TC} may not provide a reliable ∇C due to the small number of measurement points. The objective of this study is to clarify whether ∇T_{TC} or $\nabla T_{\mathrm{in\text{-}situ}}$ should be referred to in the proposed method. In this study, the spatial phase change distribution $\Delta\phi(x)$ obtained by the proposed method was compared with the in-situ observation ones to verify the certainty of the proposed method. Then, S_T was calculated referring to ∇T_{TC} and $\nabla T_{\mathrm{in\text{-}situ}}$ and compared with reference value to evaluate their respective certainty.

2. Experimental and Analysis Procedures

On the ISS “Kibo”, a longitudinal temperature difference of 30˚C was applied to homogeneous salol-2.58 mol% butyl alcohol filled in a glass container. The time variation of interference fringe intensity $I(X,t_{\mathrm{in\text{-}situ}})$ at each longitudinal position $X = 1$ to 480 pixels with the length of 2.4 mm was observed in-situ for about 8 h (until considered steady state) using a two-wavelength interferometer (532 nm and 780 nm). The observation field of view was then moved by moving the glass container at the speed of $v = 0.6$ mm·s^{-1} in the longitudinal direction. The fringe intensity outside the in-situ observation field $I(X,t_{\mathrm{move}})$ was observed alternately at two wavelengths at 3 s intervals. The values of $I(X,t_{\mathrm{in\text{-}situ}})$ and $I(X,t_{\mathrm{move}})$ were analyzed to obtain the Soret coefficients S_T with reference to ∇T_{TC} and $\nabla T_{\mathrm{in\text{-}situ}}$ in the moving observation as follows.

1st) The phase changes $\Delta\phi(X,t_{\mathrm{in\text{-}situ/move}})$ were obtained by converting $I(X,t_{\mathrm{in\text{-}situ/move}})$ using the fringe analysis method[2,3)].

2nd) The phase changes of solution $\Delta\phi_{\mathrm{s}}(X,t_{\mathrm{in\text{-}situ/move}})$ were obtained by subtracting glass container ones from $\Delta\phi(X,t_{\mathrm{in\text{-}situ/move}})$.

3rd) The spatial phase change distributions $\Delta\phi_{\mathrm{s}}(x)\big|_{t_{\mathrm{f}}}$ and $\Delta\phi_{\mathrm{s}}(x)\big|_{X}$ were obtained by converting $\Delta\phi_{\mathrm{s}}(X,t_{\mathrm{in\text{-}situ}})$ at steady time t_{f} and $\Delta\phi_{\mathrm{s}}(X,t_{\mathrm{move}})$, respectively, using the relationship among sample position x, X, v and t_{move} as shown in **Fig. 1**.

4th) ∇T_{TC} and $\nabla T_{\text{in-situ}}$ were obtained from the two thermocouples and $\Delta\phi_s(X,t_{\text{in-situ}})$ by the reported analysis[1], respectively.
5th) The spatial phase change distribution of temperature $\Delta\phi_s^T(x)|_x$ was obtained by converting each ∇T at each wavelength.
6th) The spatial phase change distribution of concentration $\Delta\phi_s^C(x)|_x$ was obtained as $\Delta\phi_s^C(x)|_x = \Delta\phi_s(x)|_x - \Delta\phi_s^T(x)|_x$.
7th) The spatial distribution of concentration change $\Delta C(x)|_x$ was obtained by converting $\Delta\phi_s^C(x)|_x$ at each wavelength.
8th) $\nabla C|_x$ was obtained by robust regression of $\Delta C(x)|_x$ connected to retain concentration difference between wavelengths.
9th) The Soret coefficient $S_T|_x$ for each X was calculated from $\nabla C|_x$ in each case referring to ∇T_{TC} and $\nabla T_{\text{in-situ}}$.

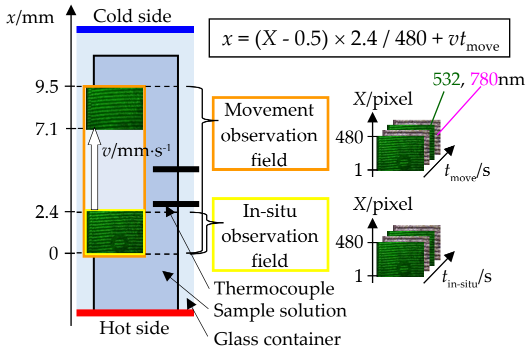

Figure 1. Schematic diagram of the way of in-situ and moving observations.

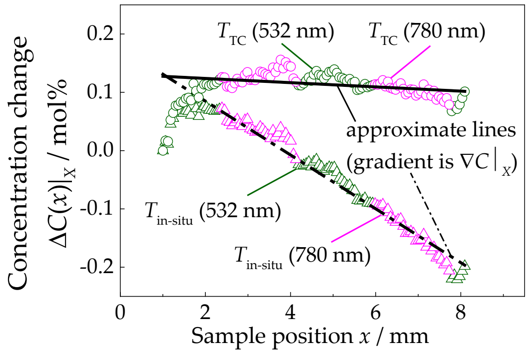

Figure 2. Example of the spatial distribution of concentration change $\Delta C(x)|_x$ at $X = 200$ pixels.

3. Results

The standard deviation of the difference between $\Delta\phi_s(x)|_{t_f}$ and $\Delta\phi_s(x)|_x$ at the same position was less than 0.7 rad for both wavelengths. The values of ∇T_{TC} and $\nabla T_{\text{in-situ}}$ were 1.39 K/mm and 1.26 K/mm, respectively. The obtained $\Delta C(x)|_x$ and $\nabla C|_x$ are shown in **Fig. 2**. The values of $S_T|_x$ referring to ∇T_{TC} and $\nabla T_{\text{in-situ}}$ averaged of all X were about 1.58×10^{-3} K^{-1} and 1.52×10^{-2} K^{-1} with error of about 90% and 4%, respectively, from the reference value[1] 1.58×10^{-2} K^{-1}.

4. Discussion

The comparison of $S_{T\text{ref}}$ and S_T calculated from each ∇T suggests that $\nabla T_{\text{in-situ}}$ is more suitable for the proposed method. When $S_T = S_{T\text{ref}}$, the ideal concentration gradient ∇C_{ide} is calculated at both ∇T. Furthermore, since the ideal phase gradient $\nabla\phi_{\text{ide}}$ is a function of ∇T and ∇C, it is uniquely determined at each wavelength for each temperature gradient. We compared $\nabla\phi_{\text{ide}}$ with the robust regressed phase gradient $\nabla\phi_s(x)|_x$ for each phase interval where no wavelength switching takes place. As a result, $\nabla\phi_{\text{ide}}$ is outside the analytical error range of $\nabla\phi_s(x)|_x$ when analyzed referring to ∇T_{TC} and is within when analyzed referring to $\nabla T_{\text{in-situ}}$. From the above, it is clear that $\nabla T_{\text{in-situ}}$ is more suitable for the proposed method than ∇T_{TC}.

5. Conclusion

In Soret coefficient S_T measurement on the ISS, we analyzed the interference fringes during the movement of the interferometer field of view during steady state and found the following. The proposed method can analyze the spatial phase change distributions with standard deviation of the difference from that of the in-situ observation less than 0.7 rad. The temperature gradient analyzed from in-situ observations should be referred to calculate the concentration distribution rather than the temperature gradient obtained from thermocouples, since the measurement error of S_T was within about 4% and the ideal phase gradient was within the error range of the analysis.

References

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