# Correlation Between Plume Color Metrics and Superconducting Properties in YBCO Thin Films Prepared by Pulsed Laser Deposition

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## Introduction

Pulsed Laser Deposition (PLD) is an effective method for depositing thin films of $YBa_2Cu_3O_y$ (YBCO). In the PLD process, a columnar ablation plasma emission, known as a plume, is observed between the target and the substrate. The shape of this plume is influenced by non-quantitative parameters such as fluctuations in laser energy, oxygen pressure, and the condition of the target. This makes it difficult to maintain a consistent environment for YBCO thin film deposition, leading to somewhat poor reproducibility of superconducting properties like the critical temperature ($T_c$) even when deposition is performed under seemingly identical conditions. To address this challenge and improve the reproducibility of YBCO thin films produced by PLD, we conducted a fundamental study focusing on how changes in the plume's visual information (RGB, HSV) correlate with changes in thin-film properties (compositional ratio, $T_c$). This paper reports on the evaluation of plume characteristics and superconducting properties under various experimental conditions and the correlation between them.

## Experimental method

YBCO thin films were deposited on $SrTiO_3$(100) single-crystal substrates using the PLD method. The plume was photographed during deposition using a depth camera (Intel Realsense Depth Camera D405). The captured images were converted to grayscale and then binarized. Based on this information, we drew a circumscribed rectangle. The binarization threshold (full range: 0-255) was fixed at 10 and 100 (Figure 1(a)). We calculated the average RGB and HSV values within the rectangle shown in Figure 1(a).For deposition, the substrate temperature was set to 920 °C, and a Nd:YAG laser (wavelength 266 nm, repetition rate 10 Hz) was used. The laser energy was varied from 10 to 20 mJ, and the oxygen pressure was changed from 0.1 to 70 Pa. For evaluation, $T_c$ was defined as the zero-resistance temperature, where the electrical resistivity dropped below 1 μΩcm, as measured by the four-probe method. The compositional ratio of the thin film was measured using SEM-EDX.

## Experimental results and discussion

Figure 1(a) shows images of the plume captured during deposition at different oxygen pressures. The

 

target is located at the bottom of the image, and the substrate is at the top. The images show that at an oxygen pressure of 0.1 Pa, the plume is a white emission only near the target. At 5 Pa, it emits a red light that extends from the target to the substrate, and at 30 Pa, this same region changes to a light closer to white. Similar trends were observed for pressures between 1 and 10 Pa (similar to 5 Pa) and between 20 and 70 Pa (similar to 30 Pa). Figure 1(b) plots the compositional ratio of Cu to Y in the thin film (Cu/3Y) against the oxygen pressure. The values are normalized so that an ideal stoichiometric ratio would be 1. The Cu/3Y ratio shows a tendency to increase with increasing oxygen pressure, with a high correlation coefficient of 0.83. This indicates that a change in oxygen pressure alters not only the plume's visual information but also the composition of Cu in the thin film. In addition, since the emission spectra of Cu and CuO are distributed in the visible light range around 520 nm and 460 nm, respectively, it is believed that the change in the composition of Cu within the plume influenced the plume's color. Figure 1(c) shows a contour plot of $T_c$ against a feature value created by multiplying the B component of RGB by the S component of HSV (B × S), and the V component of HSV. $T_c$ has a negative correlation with both B × S and V, and we found conditions for B × S and V that result in a high $T_c$. This result suggests that $T_c$ can be predicted from the plume's color information, indicating the potential for in-situ monitoring and control of superconducting properties. Future work will focus on investigating the physical meaning of the visual information (e.g., B × S, V) and its correlation with various thin-film properties.

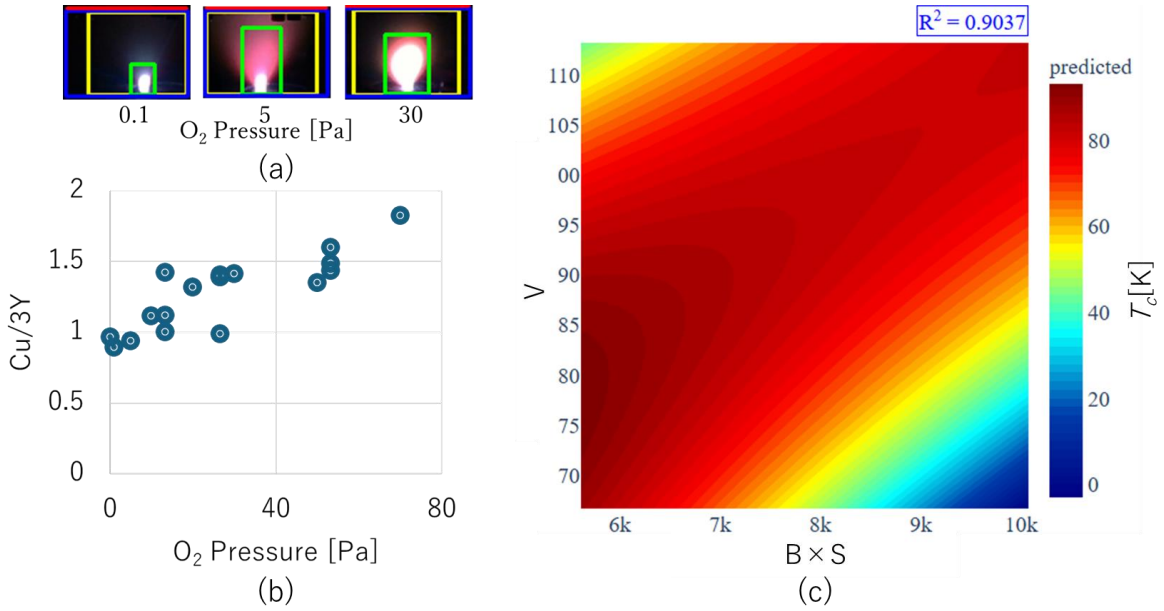


Figure 1 (a) Plume images at various oxygen pressures. The yellow rectangle corresponds to the binarization threshold of 10, and the green one to 100. (b) Compositional ratio of Cu to Y in the thin film as a function of oxygen pressure. (c) Contour plot of $T_c$ against plume color information (RGB, HSV).

**References**

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