IOCP
2024
Conference

The 1st International Online
Conference on Photonics

14–16 October 2024 | Online

MDPI

Compressed Hermite–Gaussian single-pixel imaging

Guancheng Huang, Yutong Li, Zhengjun Liu
School of Physics, Harbin Institute of Technology, Harbin 150001, China

INTRODUCTION & AIM

In contrast to the array detector, the single-pixel detector (SD) has a range of advantages, including heightened quantum efficiency, attenuated dark noise, and expedited response time. These advantages engender the extensive utility of single-pixel imaging (SPI) within numerous imaging fields. Traditional single-pixel imaging (SPI) encounters challenges such as a high sampling redundancy and poor imaging quality, constraining its widespread application. Despite a range of orthogonal modulation modes having been employed in structured illumination to enhance imaging performance, some encoding issues still persist in information sampling, impeding the further progression of SPI. We propose an SPI method based on orthogonal Hermite–Gaussian (HG) moments, achieving improved imaging reconstruction through differential modulation of HG basis patterns and linear weighting of the acquired intensity. Moreover, we incorporate compressed sensing algorithms within the framework of HG-SI, integrating moment-based sampling strategies to optimize imaging capability under sparse measurements.

Our method entails no additional setups or constraints, making it applicable to a wide range of SPI scenarios. This advancement propels the investigation of optical field modulation modes within SPI and holds promise in offering a universal solution for weak-intensity and non-visible light microscopy.

METHOD

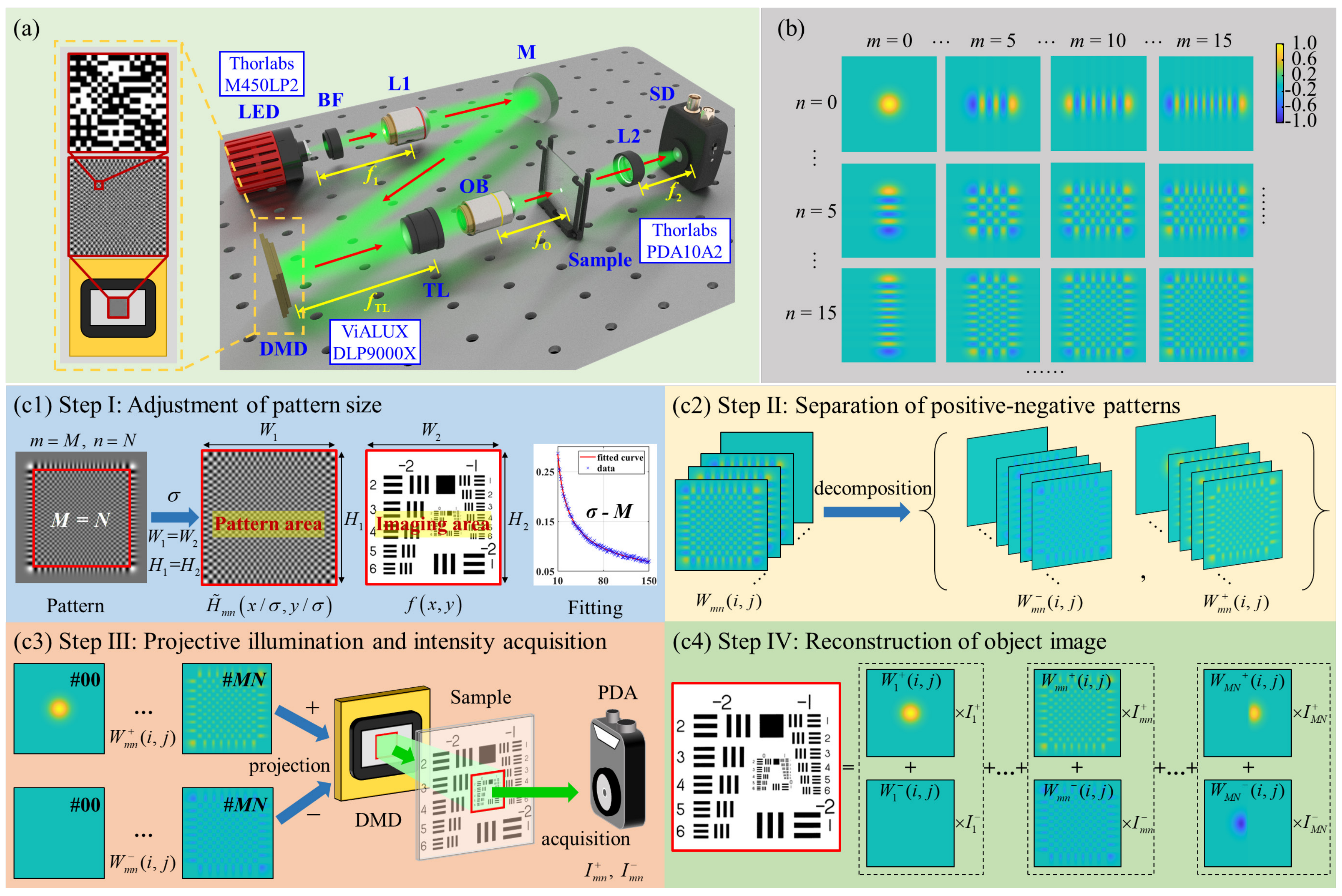

Figure 1 Experimental imaging setup. (a) Hardware system. BF, bandpass filter; L1, L2, lens; M, mirror; DMD, digital micro-mirror device; TL, tube lens; OB, objective; SD, single-pixel detector. (b) HG basis projection patterns loaded onto DMD. (c1)–(c4) Flow chart of HG-SI imaging process.

The experimental setup, as illustrated in Fig. 1(a), employs a 450 nm illumination source. In order to fully harness the high-speed binary projection capabilities of the DMD, a series of distinct binary basis patterns is loaded onto it for light field modulation. These basis patterns closely approximate grayscale patterns by utilizing the Floyd-Steinberg error diffusion algorithm.

In SPI, the measurement values of SD can be expressed as the inner product between the illumination pattern and the object image. A comparison of this expression with HG moments reveals their nearly identical mathematical forms. Therefore, by using normalized HG bases $\tilde{H}_{mn}$ for orthogonal illumination of the object, the intensity values I correspond to the HG moments of corresponding orders. The spatial distributions of 2D HG bases are depicted in Fig. 1(b). The HG-SI process, as illustrated in Fig. 1(c), is systematically elucidated into the following stages:

I. Adjustment of pattern size: HG basis patterns naturally enlarge with higher orders. To match the imaging area and ensure resolution, we adjust the range factor σ based on the maximum expansion order, guaranteeing optimal sizing of the illumination field.

II. Separation of positive-negative patterns: To address the challenge of negative modulations within HG illumination, we employ a differential encoding strategy, which enhances imaging quality by augmenting modulation quantity through the separation of positive and negative distributions within each basis pattern.

III. Projective illumination and intensity acquisition: HG basis patterns are loaded onto the DMD and projected onto the object. The light intensity in the rear optical is then measured using an SD.

IV. Reconstruction of object image: The process of object image reconstruction is achieved through the linear weighting of the measured optical intensity values with their corresponding HG orthogonal bases. The process involves the discrete selection of HG orthogonal bases for modulated illumination, the acquisition of HG weight coefficients with non-sequential orders through intensity measurements, and the opposite integration of CS optimization into the reconstruction algorithm.

RESULTS & DISCUSSION

To rigorously evaluate the imaging capability of HG-SI, we conducted several reconstructions at different sampling counts as illustrated in Fig. 2, subsequently comparing the results with those obtained through FSI and HSI. To ensure methodological parity, we maintained uniform measurement quantities and a constant imaging size of 256 × 256 pixels in simulations and experiments.

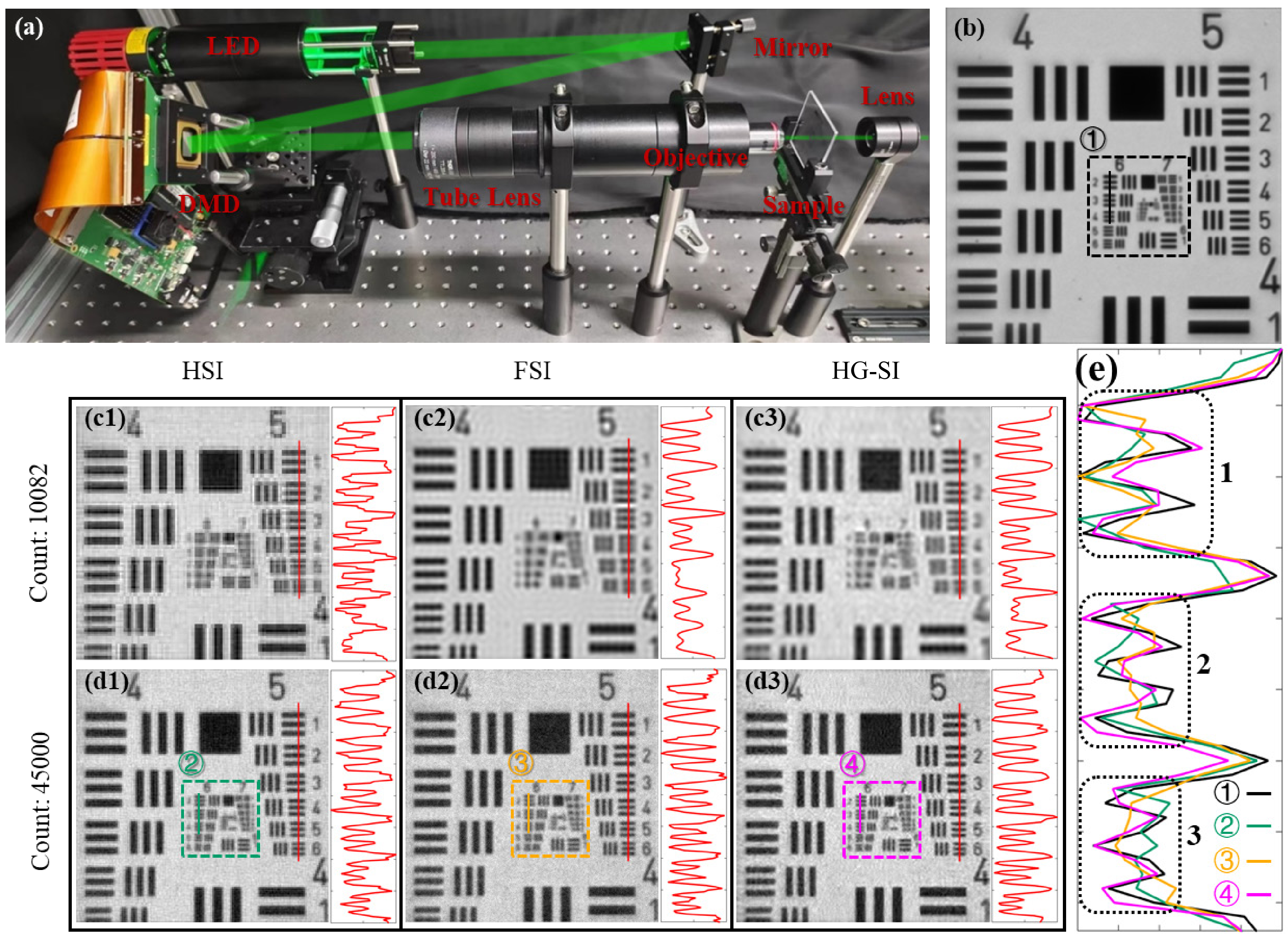

Figure 2 Experimental reconstruction of the amplitude USAF resolution target. (a) Active modulation SPI experimental system. (b) Reference image captured by an sCMOS camera. (c1-c3) Reconstructions and corresponding local profiles with HSI, FSI, and HG-SI at 10082 measurements. (d1-d3) Reconstructions at 45000 measurements. (e) Local profiles of the sixth group from (b) and (d1-d3).

When subjected to an equivalent number of measurements, HGSI consistently outperforms FSI and HSI in the imaging quality. This superiority is evident in both evaluation metrics and visual comparisons. Due to the differential encoding mode and local modulation property, HG-SI has superior noise robustness, maintaining the clear reconstruction of local features.

CONCLUSION

In summary, we introduce a compressed SPI method founded on the principles of HG moments. Our method yields superior imaging visual performance and numerical evaluation compared to FSI and HSI under identical conditions. HG-SI is anticipated to emerge as a versatile and practical solution within the realm of weak-intensity and nonvisible light imaging domains.

REFERENCES

G. Huang, Y. Shuai, Y. Ji, et. al., Appl. Phys. Lett. 124, 111108, (2024).

https://iocp2024.sciforum.net/