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Shadowgraph Imaging System Using an Intensified CCD for Underwater Electrical Wire Explosion

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1. Introduction

Underwater electrical wire explosion (UEWE) is widely used to research warm dense matter (WDM), nano-powder synthesis, and reservoir stimulation [1-3]. UEWE offers advantages such as a clear water-plasma boundary and the generation of radially uniform high-energy dense plasma [4].

The clear water-plasma boundary allows for precise measurement of average plasma density. In previous studies, a high-speed framing camera is used to image the boundary [4, 5]. However, the framing camera has a limited matrix size of 128 $\times$ 8 pixels, making it difficult to evaluate axial uniformity.

An intensified CCD (ICCD) is a charge-coupled device (CCD) combined with an image intensifier. An ICCD has a much larger matrix size of 1024 $\times$ 1024 pixels compared to that of framing camera. Thus, it is possible to evaluate the axial uniformity of the plasma and obtain a clear image of the exploding wire.

This research aims to evaluate a shadowgraph imaging system using an ICCD for underwater electrical wire explosion.

2. Methods

Fig. 1 shows a pulsed discharge system and a shadowgraph imaging system using an ICCD.

The imaging system consists of a LED light source, F/4 lenses for focusing and collimation (300 mm focal length), an aperture, an optical filter, and an ICCD (Andor, iStar 334T). The LED light source emits light with a center wavelength 660 nm and a FWHM of 20 nm. The light is focused by the focusing lens and filtered by the optical filter at 660 nm with a FWHM of 10 nm to allow a moderate level of self-emission. The resolution of ICCD is $\sim 4.2\ \mathrm{nm/pixel}$. The imaging time is controlled by a digital delay generator (BNC, model 575).

Copper wires and titanium wires, each with a diameter of 50 μm, were discharged by a 5 μF capacitor. The lengths of the copper and titanium wires were 4.5 cm and 3 cm respectively. The initially charged voltage were 2.5 kV and 3 kV for copper wires, and 2.5 kV for the titanium wire. Shadowgraph images were captured at onset of rapid current rise as shown in Fig. 2, indicating the transition of the exploding wire into vapor states. The corresponding imaging times were 5.5 μs and 5 μs for copper wires with initially charged voltages of 2.5 kV and 3 kV respectively, and 9 μs for the titanium.

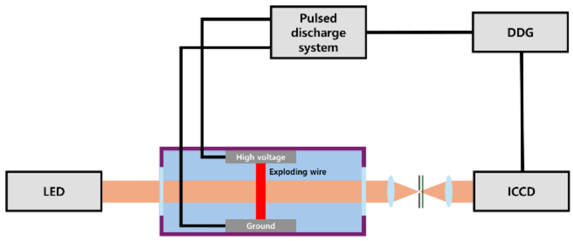

Fig. 1. Pulsed discharge system and shadowgraph imaging system using an ICCD.

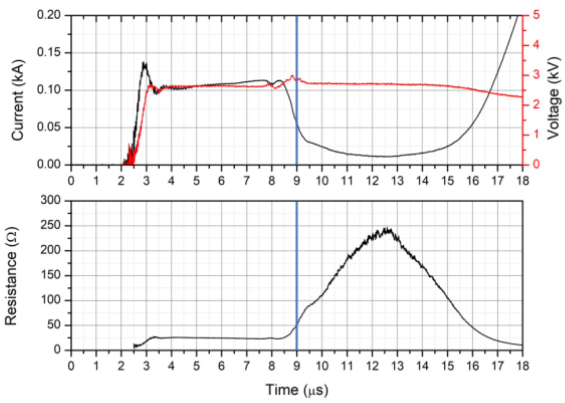

Fig. 2. A typical waveform of an exploding wire. The blue vertical line indicates an imaging time.

3. Results and Discussion

Fig. 3 presents shadowgraph images of exploding copper and titanium wires. The water-plasma boundary of the exploding copper wires appears almost axially uniform. For the copper wire with an initially charged voltage of 3 kV, a straight shock wave front is observed. Despite the overall axial uniformity, some bright and illuminating areas are observed. This instability is called as electrothermal instability (ETI) and is commonly observed when the initial energy deposition rate is too low to induce the transition of exploding wire to a supercritical state [6]. Therefore, the imaging system has enough pixel size and spatial resolution to get the water-plasma boundary and evaluate the axial uniformity.

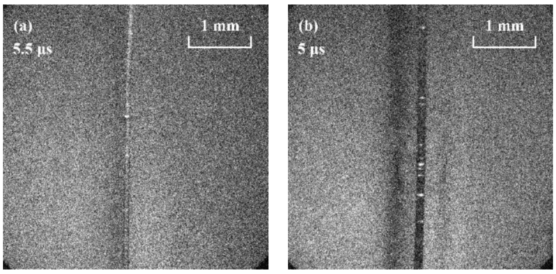

Fig. 3. Shadowgraph images of copper wire with initially charged voltages of (a) 2.5 kV and (b) 3 kV.

Fig. 4 presents the shadowgraph image of the exploding titanium wire. The axial uniformity of the exploding wire is low due to ETI, resulting in a higher presence of bright areas compared to the case of copper wires. This arises from the difference of thermodynamic and electric properties, such as vaporization enthalpy and electric conductivity, between copper and titanium. Thus, the constructed imaging system is sufficient at observing the difference in the development of the exploding wire between different metals.

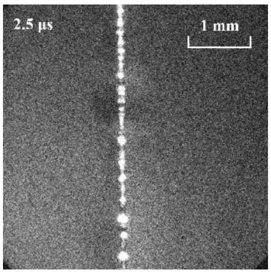

Fig. 4. Shadowgraph image of the titanium wire with initially charged voltage of 2.5 kV.

4. Conclusions

The shadowgraph imaging system using an ICCD for underwater electrical wire explosion was evaluated. The constructed imaging system has enough pixel size and spatial resolution to capture a clear water-plasma boundary and observe axial uniformity. This imaging system is useful to obtain accurate measurements of the average density of the exploding wire and explore the difference in the development of the exploding wire between different metals.

5. Acknowledgements

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REFERENCES

[1] A. W. DeSilva, and A. D. Rakhel, Progress in Measurements of the Electrical Conductivity of Metal Plasmas, Contrib. Plasma Phys.,Vol.45, pp.236-242, 2005.

[2] C. Cho, Y. W. Choi, C. Kang, G. W. Lee, Effects of the medium on synthesis of nanopowders by wire explosion process, Appl. Phys. Lett., Vol.91, 2007.

[3] Ruoyu Han, Jiawei Wu, Haibin Zhou, Yongmin Zhang, Aici Qiu, Jiaqi Yan, Weidong Ding, Chen Li, Chenyang Zhang, Jiting Ouyang, Experiments on the characteristics of underwater electrical wire explosions for reservoir stimulation, Matter Radiat. Extremes, Vol.5, 047201, 2020.

[4] Sungbin Park, Hakmin Lee, Jonghyeon Ryu, Kyoung-Jae Chung, Y. S. Hwang, Kern Lee, Deok-Kyu Kim, Measurement on the electrical conductivity of copper along the binodal curve in warm dense regime, Appl. Phys. Lett., Vol.119, 174102, 2021.

[5] Sungbin Park, Hakmin Lee, and Kyoung-Jae Chung, Liquid–vapor phase transition process during underwater electrical wire explosion, AIP Advances, Vol.13, 065002, 2023.

[6] Zhigang Liu, Yutai Li, Xinxin Wang, and Xiaobing Zou, Electrothermal instability in different modes of underwater electrical wire explosion, J. Appl. Phys., Vol.134, 233301, 2023.