URSI GASS 2023, Sapporo, Japan, 19 – 26 August 2023

High Power and Long Distance Underwater Optical Wireless Power Transmission

Tomoyuki Miyamoto, Yamato Takahashi, and Yuha Tai
Tokyo Institute of Technology; e-mail: tmiyamot@pi.titech.ac.jp

Abstract

To increase the output of the underwater optical wireless power transmission, a 450 nm - 30 W laser beam was irradiated at a 0.9 m of underwater distance and the maximum output of 3.7 W was achieved using a GaAs solar cell module using fly-eye lens system. A multilayer reflector was installed in a 90cm-long water tank to evaluate the characteristics up to a distance of 9.9m with a maximum of 10 reflections, and a solar cell output of 0.81W was achieved at a distance of 9.9m under a light output of 17.5W.

1 Introduction

Underwater and undersea areas, where only limited technologies such as sound waves can be used, are called the "last frontier". One of the reasons is that underwater equipment is powered by batteries or electrical wires. Batteries require time-consuming recharging and expensive salvage operations to replace. With electrical wires, the influence of ocean currents and limited range of motion are problems, as is the strain of handling a long wire. Therefore, the development of underwater wireless power transmission technology will greatly improve the functionality of the underwater equipment and make new various applications. Optical Wireless Power Transmission (OWPT) is the most attractive for underwater applications due to its long-distance transmission capability even underwater.

In this paper, the performance of underwater OWPT using a high-power blue laser up to 30 W and the long underwater transmission distance of about 10 m are investigated.

2 Fly-Eye Lens based Receiver

The receiver of the OWPT is a solar cell module consisting of several small cells connected in series, and it requires uniform intensity light irradiation for efficient light-to-electricity conversion. In the usual actual underwater application scenarios, light beams will be incident from different directions due to the unfixed light source system and receiver equipment. The fly-eye lens system is effective in uniformly irradiating solar cells and reducing waste light with wide tolerance for incident beam size, beam shape and incident angle, and beam transmission distance. However, the basic fly-eye lens system has a limited angle of incidence tolerance. We have proposed a method to extend the angle by installing mirrors on four sides of the optical path from the imaging lens to the solar cell [1].

Figure 1 shows the experimental results of the angular dependence of the output of the fly-eye lens module with multilayer reflectors. The fly-eye lens is an 8 cm square by 8 × 8 array. The light-receiving module is an 8 cm square of 5-cell GaAs solar cells connected in series. In this experiment, the angular dependence of the fly-eye lens system with mirror was evaluated using a blue (450 nm) laser with a maximum output power of 6 W. The beam size was expanded by a concave lens and collimated by a collimating lens.

It should be noted that without the mirror module, the solar cell output would be zero above the allowable incident angle of 14. In the angle range of 0-14, there is no difference in output between the no-mirror module and the multilayer mirror module. This is because there is no component reflected by the reflector. On the other hand, the output for the range of 14-80 was obtained from the solar cell module using the multilayer mirror module. The output decreased as the angle of incidence increased. This may be due to the angle dependence of the AR coating on the lens surface and the focal length of the lens at oblique incidence.

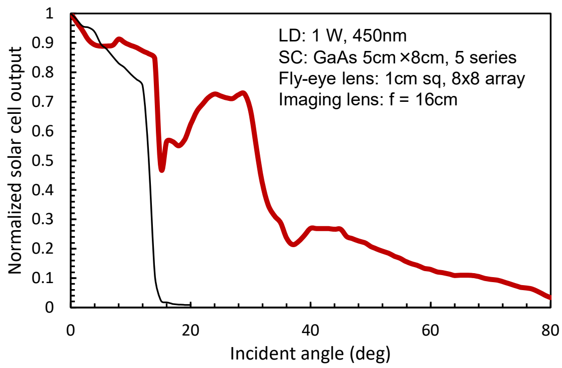

Figure 1. Incident angle dependency of fly-eye lens system with multilayer mirror. The thin black line is for the control experiment without mirror.

3 High Power Underwater OWPT

The high-power characteristics of underwater optical wireless power transmission were evaluated. The experimental setup is shown in Fig. 2. A blue (455 nm) array laser module (Nichia Corporation, NUBM37) with a maximum output power of 125 W was used as the light source. This module has 4×6 laser chips with an output area of approximately 14 mm × 18 mm. During this investigation, experiments were performed with maximum output power up to 30 W.

For underwater propagation, experiments were conducted in tap water with a propagation length of 0.9 m in a water tank. The light source and receiver modules were placed in the air outside the tan. The water tank is made of acrylic and a total Fresnel reflection loss of 9.4% is assumed at two air interfaces. The light receiver module is 8 cm square of 5-cell GaAs solar cells connected in series with the fly-eye lens module with multilayer mirror. An Al heat sink is placed on the backside of the solar cell module for heat dissipation.

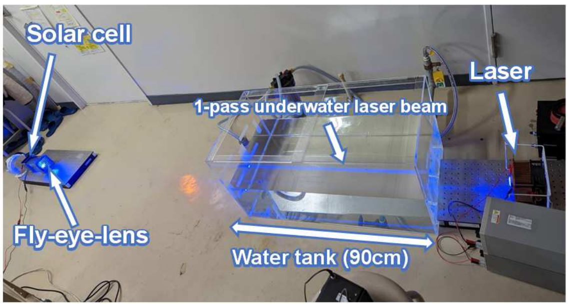

Figure 2. Experimental setup for high-power underwater optical wireless power transmission.

Figure 3 shows the experimental results of solar cell power versus light source power. At a propagation distance of 0.9 m in tap water, a solar cell power of 3.7 W was obtained at a light source power of 30 W. Although the propagation distance is about 1 m, this is the highest output power ever reported underwater. The solar cell efficiency, which is the ratio of solar cell power to light output, was about 12-13% (14-15% without the water tank). This relatively low efficiency is mainly due to the difference in photon energy and GaAs bandgap.

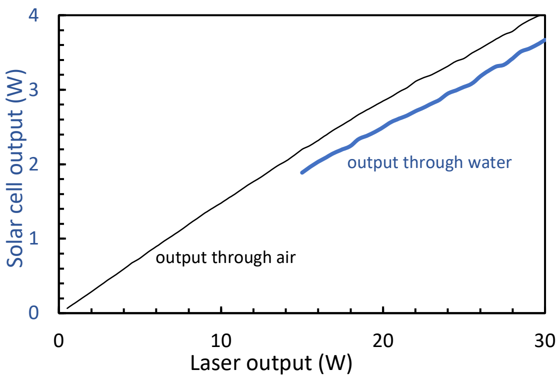

Figure 3. Experimental setup for high-power underwater optical wireless power transmission.

4 Long Distance Underwater OWPT

In this study, long-range OWPT experiments were conducted using a 0.9 m long tank by installing multilayer reflectors inside the tank [2]. A long-range, high-power OWPT experimental system with up to 10 reflections (9.9 m distance) was constructed using three 6 W laser sources with 450 nm wavelength as shown in Fig. 4. The position of the laser beams was adjusted as close as possible to an optical axis. However, with the help of the fly-eye lens system, the arrangement of the laser beam is relatively simple.

With a total light output of 17.5 W, the solar cell output power of 0.81 W was obtained at a propagation distance of 9.9 m in tap water. This result is also the record output at a long underwater distance of about 10 m. The loss coefficient of tap water estimated by varying the number of reflections was 0.152 m^{-1}, which is relatively large.

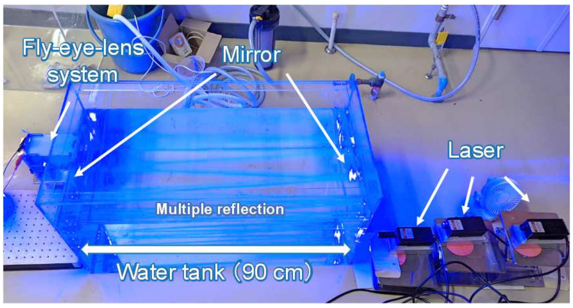

Figure 4. 10 m long class underwater light radio.

6 Conclusion

Underwater optical wireless power transmission was investigated using tap water in a water tank. A fly-eye lens system for a receiver module was used to accommodate a variety of beam injections. A solar cell output power of 3.7 W was achieved at a water propagation distance of 0.9 m. A solar cell output power of 0.81 W was achieved at a propagation distance of 9.9 m. This is the largest class of characteristics reported for both power supply distance and solar cell power output.

Acknowledgements

This work was partially supported by the Tsurugi-Photonics Foundation and the Takahashi Industrial and Economic Research Foundation. In addition, a part of this paper is based on the results of JPNP14004, a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

References

[1] Y. Tai and T. Miyamoto, "Experimental characterization of high tolerance to beam irradiation conditions of light beam power receiving module for optical wireless power transmission equipped with a fly-eye lens system," MDPI/Energies, **15**, 19, Oct 2022, 7388, doi:10.3390/en15197388.

[2] Y. Tai, Y. Takahashi and T. Miyamoto, "Experimental characterization of 10m-1W class underwater optical wireless power transmission using fly-eye lens system," *The review of laser engineering*, **51**, 3, 2023.