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A comprehensive review of optical wireless power transfer technology

Key words: Wireless power transmission; Optical wireless power transfer; Distributed laser charging; Laser diode; Solar cell

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Introduction

A comprehensive review of optical wireless power transfer (OWPT) techniques including working principle, system design, and components.

- We outline several OWPT techniques including optical beamforming, distributed laser charging (DLC), adaptive distributed laser charging (ADLC), simultaneous lightwave information and power transfer (SLIPT), Thing-to-Thing (T2T) OWPT, and high intensity laser power beaming (HILPB).
- We discuss laser selection, hazard analysis, and received photovoltaic (PV) cell selection for OWPT systems.
- We discuss a range of open challenges and counter measures.

OWPT

☐ OWPT

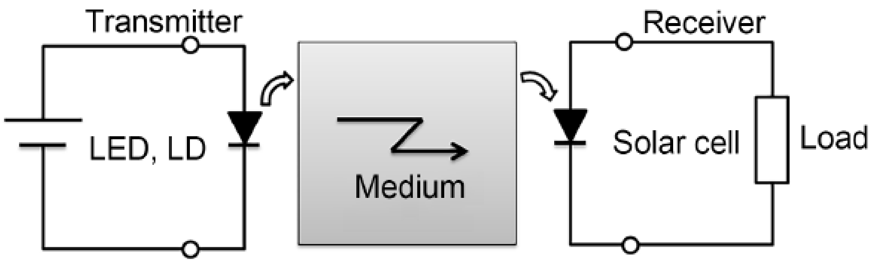

Fig. 1 Basic design of an OWPT system

OWPT is a WPT technology that uses a light source as a power transmitter. It can provide a promising solution to the problem of insufficient transmission distance. This approach can extend the transfer distance using simple system components.

☐ OWPT applications

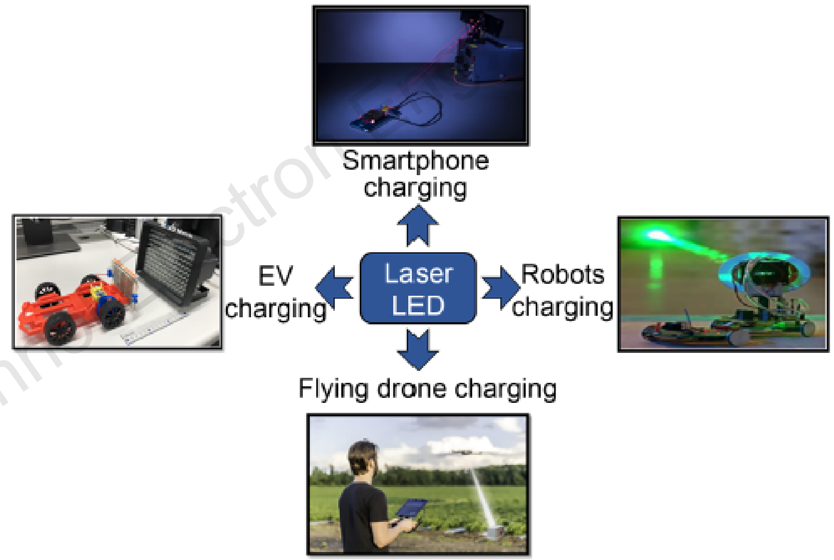

Fig. 2 OWPT applications

Several research laboratories around the world have been focusing on OWPT for various application scenarios.

OWPT projects

- Power and data transfer over light

Fig. 3 Experiment for data and power transmission

- Rover testing at night (powering rovers by high intensity laser induction on planets)

Fig. 4 OWPT based rover testing at night

- Autonomous rover

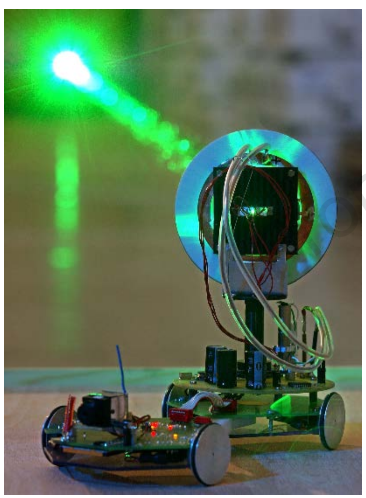

Fig. 5 EADS developed laser-powered rover

- OWPT for smartphone charging

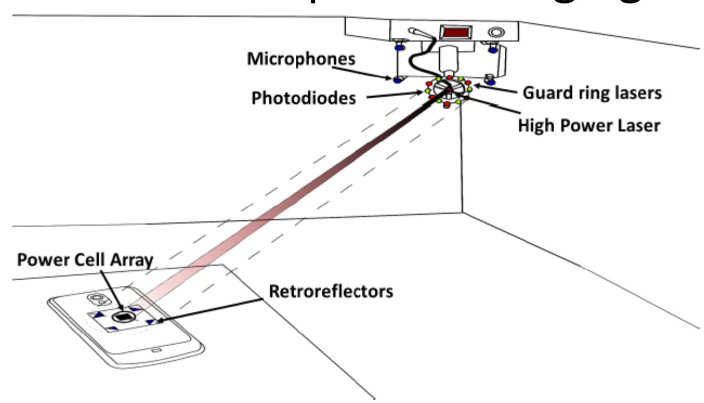

Fig. 6 Smartphone charging system

Research contributions

☐ Research contributions to OWPT

Reference	Transmitter	Receiver	Research goal
Zhou YH and Miyamoto, 2019a	High intensity IR LED	GaAs solar cell	Reporting 200 mW output power at a 100 cm transmission distance with 41.7% solar conversion efficiency and 77% optical system efficiency
Steinsiek, 2003	Green (532 nm), frequency-doubled Nd:YAG laser	Solar cell	Powering a mobile rover over a distance of 30–200 m
Hirota et al., 2015	975-nm VCSEL array	Si solar cells	Achieving 33% power generation efficiency of Si solar
Katsuta and Miyamoto, 2018	VCSEL	GaAs solar cell	Reporting an OWPT system with 15% efficiency
Crump et al., 2013	High power LDs with 940–980 nm wavelengths	–	Reporting more than 65% conversion efficiency
Fakidis et al., 2014	White LED	Si solar panel	The harvested power was 18.3 mW, and the link efficiency was 0.1%
Fakidis et al., 2015	Red LDs	Multi-c-Si solar panel	The calculated harvested power was 10.4 mW, and the link efficiency was 0.74%

OWPT techniques

Optical beamforming

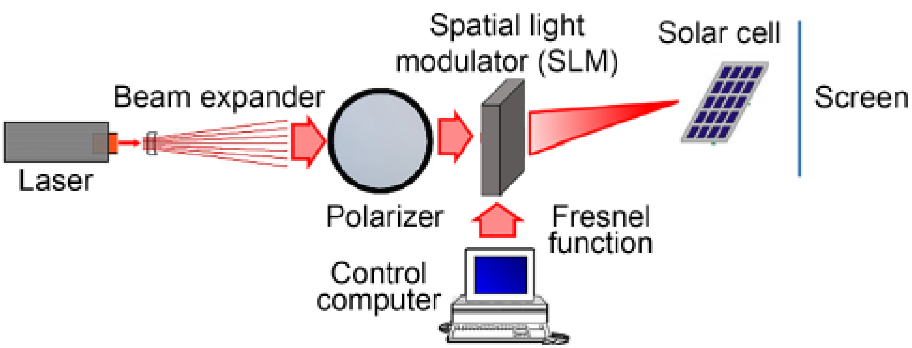

Fig. 7 Block diagram of optical beamforming

- Optical beamforming is the technology in which light from an optical source is focused on a receiver device.
- It enables wideband signal transmission and prevents beam-squint and imbalance loss effects.

Distributed laser charging (DLC)

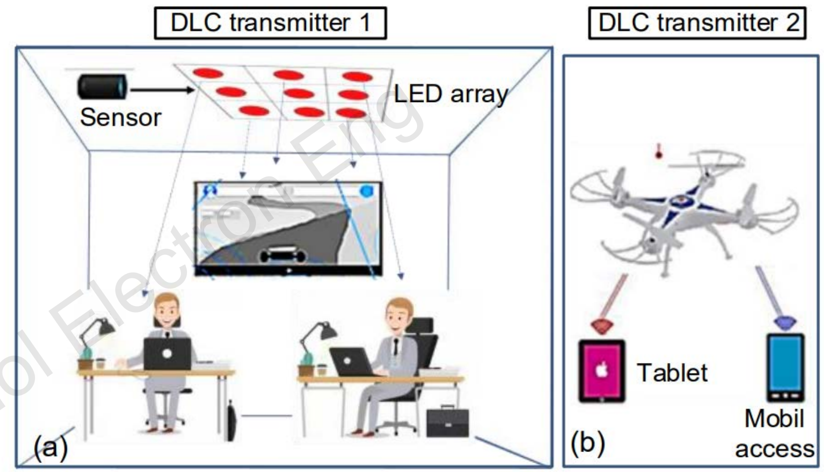

Fig. 8 DLC potential applications: (a) LED array transmission; (b) drone transmission

- The DLC method provides self-alignment to charge IoT devices without any special tracking and positioning, as long as transceivers are in line of sight (LOS) to each other.
- WPT of DLC can be stopped after blocking LOS by any intermediate object.

OWPT techniques

- Adaptive distributed laser charging (ADLC)

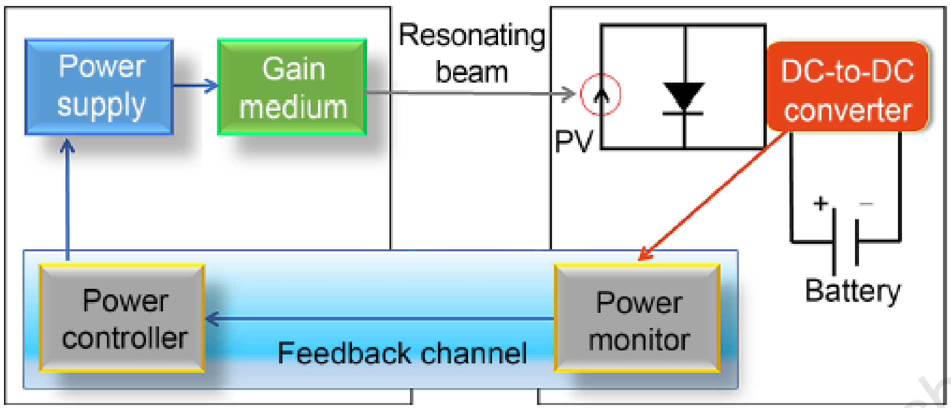

Fig. 9 Block diagram of an ADLC system

- ADLC is similar to link adaptation in wireless communication, which is used to optimize information delivery.
- In ADLC, adaptive power is transmitted on the basis of feedback information from the ADLC receiver. The ADLC technique can significantly enhance energy use.

- Simultaneous lightwave information and power transfer (SLIPT)

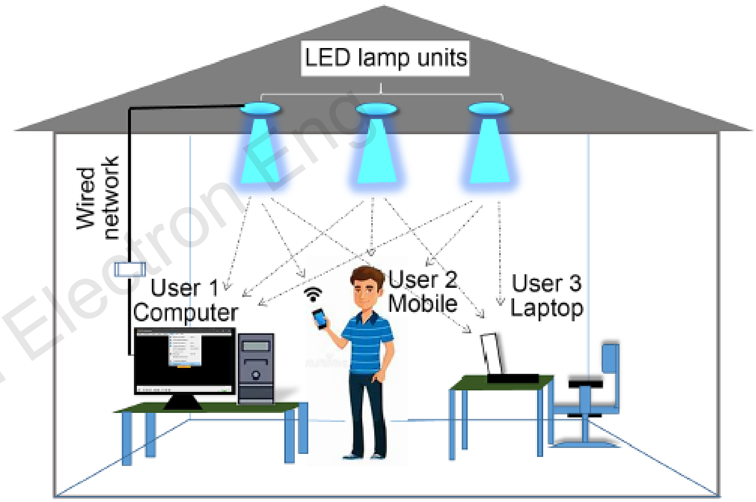

Fig. 10 SLIPT application scenario

- Using an optical source, it is possible to simultaneously deliver data and perform energy transfer.
- It can be a cost effective solution for wireless systems, e.g., autonomous self-powered devices and remote sensors.
- It is very promising for aerospace, smart house, healthcare, and underwater applications.

OWPT techniques

- Thing-to-Thing (T2T) OWPT

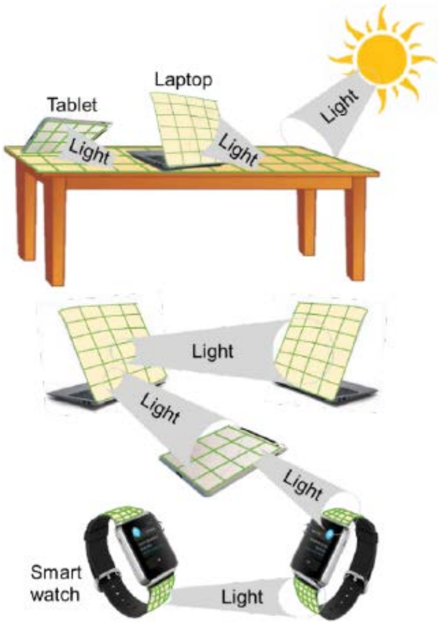

Fig. 11 A proposed T2T OWPT system

- In this proposed system, things/objects are partly or fully covered by perovskite transceivers to enable wireless charging or discharging functions.
- This idea removes the unidirectional WPT limitation and supports bidirectional OWPT between both moving and stationary objects.

- High intensity laser power beaming (HILPB)

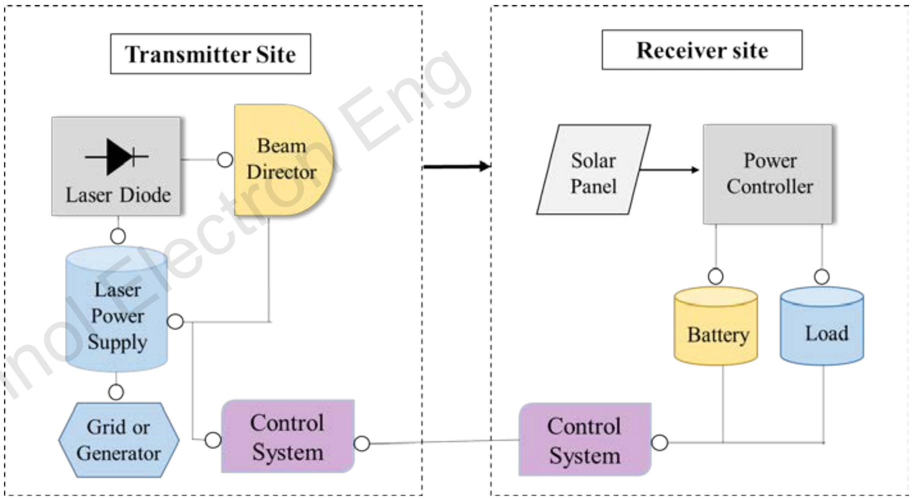

Fig. 12 A schematic diagram of an HILPB system

- HILPB is a promising technique for long-range WPT for both terrestrial and space applications.
- In an HILPB system, a high-power LD source is used because of its excellent characteristics of small size, high reliability, and high efficiency.

Transceiver selection in OWPT

☐ Laser selection

☐ PV cell selection

- Proper selection of the laser is crucial for an OWPT system.
- In principle, laser selection should comply with various constraints such as: (1) OWPT through the atmosphere or different environments; (2) the maximum required transfer energy for the OWPT system.

Table 5 Existing laser technologies (Mason, 2011)

Laser type	Wavelength (nm)	Efficiency (%)
Diode 10 kW	850	50
Fiber 10 kW	1060	25
Fiber 20 kW	1060	25
Thin disk 25 kW	1060	25

Table 6 Eye safe lasers (Kaushal and Kaddoum, 2017)

Laser type	Wavelength	Output power	Application
Nd:YAG crystal	1.06 μm	Up to 1 kW	Laser detection and ranging (LADAR)
Nd:YAG	0.532 μm / 1.065 μm	Up to 1 kW	Atmospheric communication
Raman-shifted Nd:YAG	1.545 μm	>10 kW	Light detection and ranging (LIDAR)
Fiber laser	Variable	Dozens of kW	Weapon
Nd:YAG	1.06 μm	Dozens of W	Sensor
Vertical cavity surface emitting laser (VCSEL)	1.064 μm	Dozens of W	Illuminator

Transceiver selection in OWPT

PV cell selection

- The receiver component of any OWPT system should be carefully designed for efficient conversion of optical signals into electricity. The most common conversion technologies are photovoltaic, pyroelectric, and thermoelectric.
- Among these technologies, PV technology is considered the most mature, and has the highest efficiency to deliver high power over longer distances.
- For efficient performance, laser power, wavelength, PV cell material, and temperature should be taken into account.

Table 9 Efficiencies of various PV materials (Miyamoto, 2018)

Work plan	LD type	LD efficiency (%)	Solar cell type	Solar cell efficiency (%)	WPT efficiency (%)
Current	Common LD	35	Si-SC	30	10
	Common LD	35	GaAs-SC	50	17
	Best LD	74	Best GaAs-SC	66	49
Future	GaAs	85	Si	50	43
	GaAs	85	GaAs	75	64
	GaN	85	GaN	85	72

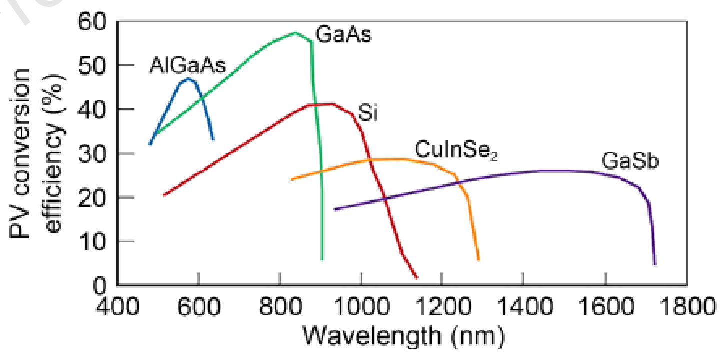

Fig. 13 Spectral response of PV materials (Mason, 2011)

Challenges in OWPT

- ☐ Efficiency improvement issue
- ☐ Safety concerns
- ☐ Optical communication problem
- ☐ Propagation losses in the optical beam
- ☐ Thermal effects on system performance
- ☐ Pointing issue
- ☐ Collimation of multi-mode lasers

Conclusions

- In this study, the basic concepts of OWPT have been presented.
- In particular, the OWPT working principle, system design, potential features, and various OWPT projects for mainstream applications are discussed.
- We have also suggested that OWPT is an essential element to supply power to IoT terminals.
- We have highlighted the impacts of dynamic OWPT. Moreover, our study dealt with the rudimentary physics of OWPT technologies including optical beamforming, DLC, ADLC, SLIPT, HILPB, and T2T OWPT.
- We also shed some light on research efforts dedicated to these OWPT technologies.
- Besides introducing the OWPT theory, this survey provides a practical guideline for OWPT system design.
- We have given a comprehensive overview of OWPT technology and basic principles, and the challenges involved in implementing OWPT technology with regard to suitable laser and PV cell selection. We have discussed a range of open challenges and counter measures. We believe that this review will be helpful in integrating research and eliminating technical uncertainties, thereby promoting progress and innovation in the development of OWPT technologies.

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