OWPT2024 | Oral Presentation

Session 8

Session Chair: Masakazu Arai (Univ. of Miyazaki)

Thu. Apr 25, 2024 3:30 PM - 5:00 PM 304 (Pacifico Yokohama Conference Center)

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[OWPT8-01(Invited)] Near-UV photoelectric transducers for OWPT systems based on GaInN multiple quantum-well structures

*Makoto Miyoshi[1] （1. Nagoya Institute of Technology）

3:30 PM - 4:00 PM

[OWPT8-02] Study of Laser Power Converters based on GaN for High Power Applications

*Javier F. Lozano[1], Natalia Seoane[1], Enrique Comesaña[2], Florencia Almonacid[3], Eduardo F. Fernández[3], Antonio García-Loureiro[1] （1. Centro Singular de Investigación en Tecnoloxías de Información (CiTiUS), Departamento de Electrónica e Computación, Universidade de Santiago de Compostela, 2. Escola Politécnica Superior de Enxeñaría, Campus Terra, Universidade de Santiago de Compostela, Lugo, 3. Advances in Photovoltaic Technology (AdPVTech), CEACTEMA, University of Jaén）

4:00 PM - 4:15 PM

[OWPT8-03] Incident Laser Wavelength dependence of temperature characteristics of InGaN solar cells for optical wireless power transmission

*Junichi Suzuki[1], Shunki Hayashi[1], Shunsuke Shibui[1], Masahiro Koga[1], Ryusei Takahashi[1], Reo Aoyama[1], Takahiro Noguchi[1], Takahiro Fujisawa[2], Toshihiko Fukamachi[3], Koichi Naniwae[3], Shiori Ii[4], Ruka Watanabe[4], Makoto Miyoshi[2], Tetsuya Takeuchi[4], Satoshi Kamiyama[4], Shiro Uchida[1] （1. Chiba Institute of Technology, 2. Nagoya Institute of Technology, 3. Ushio Inc, 4. Meijyo University）

4:15 PM - 4:30 PM

[OWPT8-04] Effective placement methods of light source infrastructure for dynamic EV charging using optical wireless power transmission

*Mahiro Kawakami[1], Yusuke Suda[1], Tomoyuki Miyamoto[1] （1. Tokyo Institute of Technology）

4:30 PM - 4:45 PM

[OWPT8-05] Suppression of water wave effects in blue laser-based underwater-to-air OWPT by a fly-eye lens system

*Tatsuhisa Koiwa[1], Yamato Takahashi[1], Tomoyuki Miyamoto[1] （1. Tokyo Institute of technology）

4:45 PM - 5:00 PM

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[OWPT8-02] Study of Laser Power Converters based on GaN for High Power Applications

*Javier F. Lozano[1], Natalia Seoane[1], Enrique Comesaña[2], Florencia Almonacid[3], Eduardo F. Fernández[3], Antonio García-Loureiro[1] (1. Centro Singular de Investigación en Tecnoloxías de Información (CiTiUS), Departamento de Electrónica e Computación, Universidade de Santiago de Compostela, 2. Escola Polité cnica Superior de Enxeñaría, Campus Terra, Universidade de Santiago de Compostela, Lugo, 3. Advances in Photovoltaic Technology (AdPVTech), CEACTEMA, University of Jaén)

To overcome the main limitations of the high power laser transmission technology, we present modeled laser power converters made of gallium nitride, which open a path to broaden the applications in extreme environmental conditions.

The 6th Optical Wireless and Fiber Power Transmission Conference (OWPT2024), Online/Venue hybrid, Japan, Apr. 23 - 26, 2024

Study of Laser Power Converters based on GaN for High Power Applications

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***Abstract**: Wide bandgap semiconductors can improve the efficiency of the high power laser transmission (HPLT) technology due to the reduction of series resistance and intrinsic entropic losses. We present modeled laser power converters (LPCs) made of GaN for a wide range of power densities. Results show that GaN-based LPCs can improve the efficiency of the technology up to 84% at 100 W/cm^2. Using this material can broaden the range of HPLT applications due to its high resilience to extreme environmental conditions.*

1. Introduction

High power laser transmission (HPLT) has been pointed out as one of the most promising technologies for far-field wireless power transfer[1], providing electrical isolation and avoiding electromagnetic interferences when remote-delivering power[2]. This technology allows to transfer power without copper wires through optic fiber, atmosphere, water or free space. The applications of this technology are numerous, such as transferring power and data simultaneously[3] or optically powering remote antennas[4], aerial vehicles[5] or even satellites[6]. In this work we propose new laser power converters (LPCs) based on GaN for HPLT in two scenarios, considering the highest and lowest surface recombination (SR) velocities found in the literature, and we compare their efficiency with state-of-the-art for a wide range of input power conditions.

2. Materials

Current state-of-the-art of LPCs is dominated by GaAs[7]. However, recent studies suggest that a high bandgap energy will reduce the intrinsic entropic losses[8]. Besides, a higher bandgap implies fewer and more energetic photons for the same laser power density, thus reducing the ohmic losses. High bandgap materials could open a route towards efficiently converting ultra-high laser power densities. Cubic silicon carbide (3C-SiC) has been recently proposed as a promising material candidate for a new generation of high-efficient LPCs[9]. Other wide bandgap material, Gallium nitride (GaN), that could be a potential candidate for LPCs has been extensively used in LEDs and power electronics[10].

		GaAs	3C-SiC	GaN
Bandgap	eV	1.42	2.35	3.39
Thermal Conductivity	W/cmK	0.5	4.2	2.2
Melting Point	ºC	1238	2730	2500
Electron Mobility	cm^2/Vs	8000	950	2000
Hole Mobility	cm^2/Vs	390	70	170
α	cm^{-1}	12300	95	84000

Table 1. Properties of semiconductor candidates for LPC.

Some of the main properties of GaAs, 3C-SiC and GaN are summarized in Table 1. GaAs dominates the LPC state-of-the-art due to a high carrier mobility and a bandgap higher than silicon, but its low thermal conductivity and melting point limit its use for high power transmission. GaN has higher carrier mobility and bandgap than the 3C-SiC, but its thermal conductivity is lower. The silicon carbide thermal properties make it a sound candidate to manage the extreme conditions present for instance in space environments.

3. Results

In this work we present a comparison of modeled GaN-based LPCs with other state-of-the-art devices, including modeled 3C-SiC LPCs previously reported by the authors. We use Silvaco Atlas[11], a widely used TCAD tool to model all kind of semiconductor devices, including LPCs[9]. To model these structures we used the conventional horizontal laser power converter architecture (hLPC), see a scheme in Figure 1.

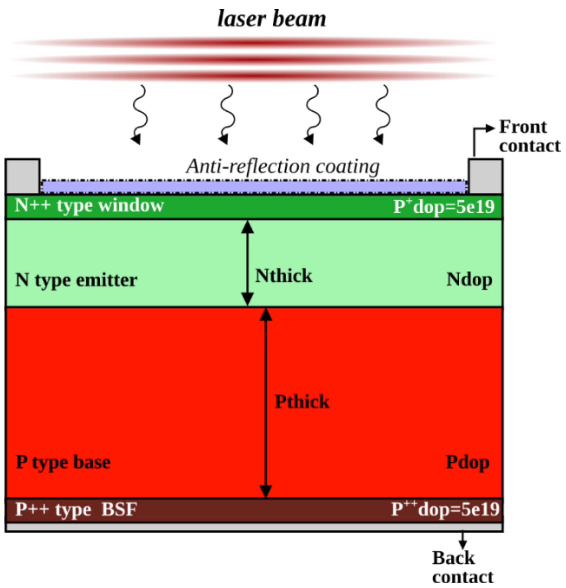

Fig. 1. 2D scheme of the hLPC architecture. The thickness and doping values of the window layer and back surface field (BSF) layer are fixed in the optimization process.

In these 2D simulations the third dimension (depth, not pictured in Figure 1) is automatically fixed to 1 μm. The width of the devices is fixed to 10 μm to save computational costs. The shadowing of the front contacts is fixed to 3% of the total width. Since the illumination area of these devices is small due to computational limitations, we model the contacts ohmic losses by scaling the contact resistances. This scaling is proportional to the difference between the illumination area of our modeled devices and the standard illumination area of an LPC, which is 10x10 mm^2[12].

We optimized GaN based hLPCs for laser power densities ranging from 1 to 3000 W cm^{-2} using an iterative algorithm, sweeping the design parameters of the devices, being these the N and P layer thicknesses and doping values. We considered two scenarios for the GaN hLPCs: 1) with the highest surface recombination (SR) velocity reported in literature ($7.5 \cdot 10^4$ cm/s) and 2) with the lowest SR ($5 \cdot 10^3$ cm/s)[13]. The efficiency of these devices is shown in Figure 2. For comparison, we include the previously reported 3C-SiC hLPCs and two GaAs based state-of-the-art devices, the current best performance cell, developed by Helmers[14], which achieves a 68.9% efficiency at 11 W cm^{-2} and suffers from series resistance losses at higher laser power densities; and the best multijunction LPC, a 5-cell VEHSA developed by Fafard et al.[15], which achieves a 66.3% at 150 W cm^{-2}. The proposed GaN LPCs show a very similar performance to that of the 3C-SiC LPCs for the 1-100 W cm^{-2} range, achieving efficiencies between 78% and 84%, outperforming state-of-the-art cells by more than 12% in their respective laser power density values. Note that the GaN hLPCs most affected by SR losses ~ 2% efficiency with respect to the GaN hLPCs with less SR, at all laser power densities. The low efficiency degradation due to SR is related to the GaN high bandgap, since the SR follows a decreasing trend when increasing the bandgap energy[13]. At 1000 W cm^{-2} the 3C-SiC hLPCs suffer severe degradation due to series resistance losses, decreasing to a 58.2% value, while the GaN hLPCs manage to achieve efficiencies of 77.5%/79.6% for the most and least affected hLPCs by SR, respectively.

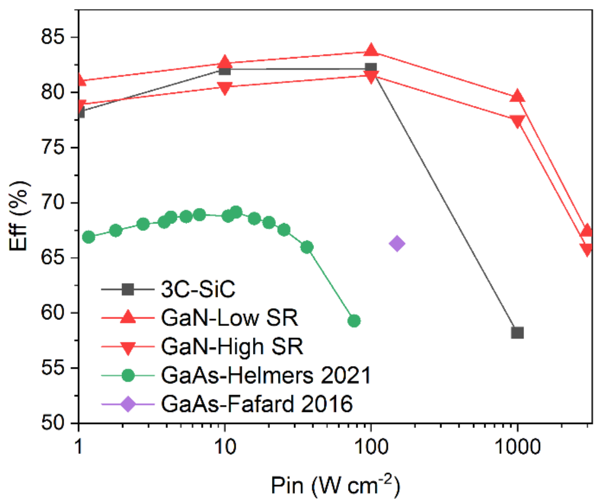

Fig. 2. Efficiency vs laser power density (Pin) of the proposed GaN hLPCs with low and high surface recombination values, and other state-of-the-art devices[9], [14], [15].

The GaN hLPC performance is less affected by series resistance losses for the same laser power density than the 3C-SiC, due to the higher bandgap energy, which produces a lower output current by increasing the voltage. Indeed, the GaN hLPC manages to convert the laser power density of 3000 W cm^{-2} with an efficiency of 65.9/67.4% (highest/lowest SR values).

4. Conclusion

In this work we explored the suitability of GaN, a wide bandgap semiconductor, as base material for LPCs, focusing on HPLT applications. The GaN LPCs show great potential, exceeding the current experimental best performance by more than 10% efficiency at all laser power densities. When compared to 3C-SiC LPCs previously reported by the authors, the GaN LPCs suffer less efficiency degradation due to series resistance than 3C-SiC ones and perform better at high laser power densities. This is due to the larger bandgap energy of GaN, which also reduces the surface recombination losses. However, the 3C-SiC has better properties when focusing on space applications. Future work will address the issue of thermal management of semiconductor candidates under extreme environmental conditions.

Acknowledgment

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