



Project OxyGaN

Project number: 7363

m-era.net 2019 programme

Deliverable D.17 - Report

Final public report

Month of delivery: M36

Results achieved

WP1. Development of GaN test structures
The task lasted for two months in the reporting period. During that time, the final structures were developed and transferred to WP6 and WP7.
WP2. Development of ZnMgO:Al tuned to the desired wavelength and conductivity
This task was finished before the reporting period started. In summary of the task which finished during the previous reporting period, we developed a state-of-the-art ZnO:Al (AZO) film deposition technology and a new approach to deposit ZnMgO:Al (AZMO) films. We compared various ways of material deposition and showed how they differ from one another.
WP3. Development of ZnMgO:Al-based contacts to N-face n-GaN
This task was finished before the reporting period started. In summary of the task which finished during the previous reporting period, we developed an optimal approach to contact formation to N-face n-GaN using an AZO film with interfacial metallic layer and plasma pre-treatment of the surface. The details of this solution cannot be yet made public.
WP4. Development of ZnMgO:Al-based contacts to Ga-face p-GaN
This task was finished before the reporting period started. In summary of the task which finished during the previous reporting period, we developed two optimal approaches to contact formation to Ga-face p-GaN using AZO films with interfacial metallic layers. The details of this solution cannot be yet made public.
WP5. Advanced characterization
TEM, EDS, XPS and TOF-SIMS characterization of AZMO films as well as in-depth characterization of the best contacts from WP3 and WP4 was carried out and helped understand the mechanisms of film growth and contact formation.
WP6. Contact validation in diode structures
The technology for determining the ohmic contact properties, regardless of their type (metallic or oxide-based) or thickness was finalized and adopted for use with laser diode devices. The technique was applied to the determination of contact resistivities for four processed laser device types: with standard n-GaN (Ti/Al/TiN/Au) and p-GaN (Ni/Au) contacts, with standard p-GaN and AZO-based n-GaN contacts (nAZO), with standard n-GaN and AZO-based p-GaN contacts (pAZO) and with AZO-based n-GaN and p-GaN contacts (allAZO). The AZO-based contacts were the ones developed in WP3 and WP4. The current-voltage (I-V) characteristics of these devices were analyzed. Operating voltages were determined for selected currents and the effective resistances of the devices were calculated. From the I-V characteristics for high currents (in the range of 40-150mA), series resistances (differential resistances) were determined for individual types of contacts. Although the differences in series resistance are not large, the best results are achieved for lasers with lower and upper contacts based on AZO (allAZO). In summary of the task, in the light of electrical parameters, AZO-based contacts seem to be comparable to conventional contacts, but contact aging tests should ultimately be decisive. Based on the properties of oxide materials and contacts, it can be expected that oxide-based contacts will constitute an anti-diffusion barrier for metal migration and prevent decomposition of the semiconductor under the contact during laser operation, which will allow the contacts to operate stably for a long time.
WP7. Demonstrating an operational packaged LD
The same laser variants as described in WP6 (standard, nAZO, pAZO, allAZO) have been implemented in the production cycles of nitride lasers. Each variant required an individual approach to processing and appropriate cycle modifications to first create a matrix of lasers, which were then divided into individual devices and mounted in TO56 housings. Each of these lasers is treated as a demonstrator. The lasers prepared in this way were subjected to standard testing procedures:

measurements of initial parameters (such as voltage and current at the laser action threshold, emission wavelength) and tests of the device's lifetime (e.g. monitoring changes in the threshold current, operating current and voltage). The lifetime test lasted 100 hours, during which the device was powered by direct current at stabilized optical power and at a constant temperature.

The details of these results cannot be publically given at this time, however it can be said that the laser diodes with AZO-based contacts all exhibited lasing and their stable performance enables to state that the goals of the project were reached.

In summary of this task, mounted laser diode demonstrators were prepared and their optical, electrical and lifetime tests were carried out. The achieved results satisfy the initial assumptions and meet the project goals.

Dissemination of results

Work and conference name	Presentation type
Wójcicka A., Fogarassy Z., Kravchuk T., Saguy C., Kamińska E., Perlin P., Grzanka S., Borysiewicz M.: "ZnO:Al with Ultrathin Subcontact Layers as Contacts to p-type GaN for High-Efficiency Blue LDs", 9th Workshop on Physics and Technology of Semiconductor Lasers 2022 (PTSL2022), Kraków 02-06.10.2022	Oral
Schavion D., "Ge doping for strain-free cladding layers in InGaN/GaN lasers", 9th Workshop on Physics and Technology of Semiconductor Lasers 2022 (PTSL2022), Kraków 02-06.10.2022	Oral
Fogarassy Z., Labar J., Wójcicka A., Kravchuk T., Kamińska E., Perlin P., Grzanka S., Borysiewicz M.: "TEM Structural Characterization of AZO Layers Deposited by Sputtering on Ga and N Polar Substrates", European Materials Research Society Fall Meeting and Exhibit (EMRS2022), Warsaw 19-22.09.2022	Poster
Wójcicka A., Fogarassy Z., Racz A., Dodony E., Kravchuk T., Borysiewicz M.: "Sputter Deposition of Zn _x Mg _{1-x} O:Al Conducting Thin Films with Controllable Band-Gap and Transparency", European Materials Research Society Fall Meeting and Exhibit (EMRS2022), Warsaw 19-22.09.2022	Poster
Taube A., Borysiewicz M., Sadowski O., Wójcicka A., Tarenko J., Wzorek M.: "Development of All-Oxide Transparent Vertical ITO and AZO b-Ga ₂ O ₃ Schottky Diodes", European Materials Research Society Fall Meeting and Exhibit (EMRS2022), Warsaw 19-22.09.2022	Poster
Wójcicka A., Fogarassy Z., Kravchuk T., Saguy C., Kamińska E., Perlin P., Grzanka S., Borysiewicz M.: "Strategies for Interface Modification of n-type N-face GaN and p-type Ga-face GaN to Obtain Transparent Ohmic Contact Using ZnO:Al for Blue to Violet LDs", European Materials Research Society Fall Meeting and Exhibit (EMRS2022), Warsaw 19-22.09.2022	Oral
S. Grzanka, E. Kamińska, I. Levchenko, J. Smalc-Koziorowska, P. Perlin, A. Wójcicka, M.A. Borysiewicz, InGaN laser diodes with ZnO – Al-based contact layers, International Workshop on Nitride Semiconductors, Berlin 9-14.10.2022	Oral

Levchenko I., “ Interface state effect on the properties of a Pd-based contact on p-GaN”, International Workshop on Nitride Semiconductors, Berlin 9-14.10.2022	Poster
Wójcicka A., Grzanka S., Fogarassy Z., Racz A., Dodony E., Kravchuk T., Levchenko I., Kamińska E., Perlin P., Borysiewicz M.: "Testing Sputter Deposited ZnMg1-xO:Al Conducting Thin Films in LD Structures as p-GaN Ohmic Contacts and Cladding Layers", Materials Research Society Fall Meeting (MRSFM22), Boston 27.11-02.12.2022	Poster
Wójcicka A., Fogarassy Z., Kravchuk T., Saguy C., Kamińska E., Perlin P., Grzanka S., Borysiewicz M.: "Transparent Ohmic Contacts to p-GaN by AZO with Subcontact Layers", Materials Research Society Fall Meeting (MRSFM22), Boston 27.11-02.12.2022	Oral
Wójcicka A., Fogarassy Z., Racz A., Kravchuk T., Borysiewicz M.: „Complex studies of room temperature magnetron sputtering growth of ZnO:Al thin films”, Conference on Reactive Sputter Deposition (RSD 22), online 7-9.12.2022	Oral
Przemysław Wiśniewski “Quantum gravimetry” - VIIth IWC PAN Winter Workshop - KALATÓWKI, Zakopane, Polska, 26-31 March 2023	Oral
Iryna Levchenko “Mono or multilayer palladium contacts to p-GaN” - VIIth IWC PAN Winter Workshop - KALATÓWKI, Zakopane, Polska, 26-31 March 2023	Oral
A. Wójcicka, Z. Fogarassy, A. Rącz, E. Dodony, T. Kravchuk, C. Saguy, E. Kamińska, P. Perlin, I. Levchenko, S. Grzanka and M.A. Borysiewicz, „Controlling the band gap and transport properties of sputter-deposited AZO thin films by alloying with Mg - solutions for optoelectronic devices", 1st Croatian Ceramic Society International Conference, 26–29.04.2023, Dubrovnik, Croatia	Invited talk
S. Grzanka, A. Wójcicka, E. Kamińska, I. Levchenko, Ł. Marona, A. Kafar, P. Perlin, M. A. Borysiewicz and TopGaN Processing Team „AZO as a contact layer for InGaN laser diodes” - VIIth IWC PAN Winter Workshop - KALATÓWKI, Zakopane, Polska, 26-31 March 2023	Oral
S. Grzanka, E. Kamińska, A. Wójcicka, M. A. Borysiewicz, P. Perlin "Performance of oxide-based versus to metal-based contacts for InGaN laser diodes" - 14th International Conference on Nitride Semiconductors (ICNS-14) Fukuoka, Japan, November 12-17, 2023; https://icns14.jp/ap.html	Oral

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