Project OxyGaN

Project number: 7363

m-era.net 2019 programme

Deliverable D.16 - Report

Y2 public report

Month of delivery: M24

Results achieved

WP1. Development of GaN test structures

The following were designed and grown for research in tasks WP2, WP3, WP4, WP6 and WP7:

- Epitaxial layers p-GaN/sapphire, p+-GaN/p-GaN/sapphire,
- n-GaN single crystal substrates with an epi-ready surface with N polarity,
- Laser structures on a GaN crystal substrate for testing and verification of AZO-based ohmic contact technology,
- Laser structures on a crystalline GaN substrate for technology testing of the possibility of using the AZO layer as the upper cladding layer in a laser structure,
- Full laser structures with thinned cover layers – for testing laser properties at IWC PAN.

WP2. Development of ZnMgO:Al tuned to the desired wavelength and conductivity

The results of work on the low resistivity ZnO:Al (AZO) were published in the journal Vacuum.

The research on comparing the ZnMgO:Al (AZMO) films deposited from AZMO targets, composite targets and cosputtering was carried out. We showed that by increasing the content of Mg in the AZMO target, it is possible to scale the Mg content in the AZMO films, in the Zn sublattice achieving bandgap engineering without the darkening effects seen in the co-sputtering or composite target experiments. However, the Mg increase lead also to a lowering of the film conductivity due to a wider bandgap. Trials with AZMO targets containing more than the standard amount of the aluminum dopant did not improve the resistivities. At the same time, the AZO that was developed in the project has so many carriers, that its energy gap is blue-shifted to the value achieved for AZMO with over 15% of Mg. Since this material is very highly conductive and has an appropriately wide bandgap, it was chosen for further tests in the contact structures.

In summary of the task which finished during the reporting period, we developed a state-of-the-art AZO film deposition technology and a new approach to deposit AZMO films. We compared various ways of material deposition and showed how they differ from one another.

Based on the results achieved on AZO and AZMO in the OxyGaN project, a project application was submitted to the m-era.net 2022 call for IR-blocking coatings.

WP3. Development of ZnMgO:Al-based contacts to N-face n-GaN

The work in WP3 was continued on the same type of substrates, delivered from WP1 and using the AZO developed in WP2. No metallic interfacial films yielded fully ohmic contacts, however symmetrical I-V curves were observed. Low work function metals, closer to GaN electron affinity were also studied but the I-V characteristics were asymmetric and the currents much lower than for the transition metals used before.

A wide array of surface modification approaches was tested to further improve the properties of the best contacts. We tested the solutions of HCl, buffered HF, NaOH and DMSO as well as plasma etching prior to contact deposition, the final being the optimal approach. It does not yield completely symmetrical I-V characteristics, however improves the current intensities. Since the n-GaN contact has a large area, the nonidealities should be compensated in the device.

In summary of the task which finished during the 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

The work in WP4 was continued on the same type of substrates, delivered from WP1 and using the AZO developed in WP2. In contrast to WP3, two metallic interfacial films yielded fully ohmic contacts. Based on characterization data from WP5, interface mixing and diffusion of the elements was closely studied to understand the mechanism of contact formation. In the two different metals, the mechanisms were different. In one case, there was strong influence of Ga-outdiffusion from the p-GaN film, in the other - the outdiffusion was blocked and interfacial solid-state reactions seemed to govern the contact formation.

AZMO films were tested as ohmic contacts to p-GaN and they did behave in a similar way as pure AZO, slightly lowering the formation temperature, however not yielding better contacts than the ones

with the two metal films. In summary of the task which finished during the 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 task ran for 4 months during the reporting period. In this time, a technology for determining the ohmic contact properties, regardless of their type (metallic or oxide-based) or thickness was started to be developed and will be continued in the following year. This approach utilizes vertical current flow, as is the case in the laser diodes and other p-n devices, contrary to the cTLM technique, which is easier to screen contact properties, but may be not exact for device applications. Technology of p-n diodes was further developed by improving Mg activation in the p-GaN layers after annealing in hydrogen. First p-n diode structures were developed and tested before being used for AZO contact tests.
WP7. Demonstrating an operational packaged LD
Several processing tests were carried out on the laser structures from WP1 covered with p-GaN contacts from WP4. Although the surface finishes were not ideal, the devices were processed into laser bars and tested for optical emission. One of the two contacts developed in WP4 proved to give better parameters of the laser diodes and it was chosen for further tests. Initial lifetime tests were carried out, proving good stability under a constant current bias, reaching 2000 hours.

Dissemination of results

Publication	Journal, impact factor
Aleksandra Wójcicka, Ildikó Cora, János Lábár, Zsolt Fogarassy, Adél Rácz, Tatyana Kravchuk and Michał A. Borysiewicz, „Multifactorial investigations of the deposition process – material property relationships of ZnO:Al thin films deposited by magnetron sputtering in DC, pulsed DC and RF modes using different targets”	Vacuum 203 (2022) 111299, IF = 4

Work and conference name	Presentation type
Aleksandra Wójcicka, Ildikó Cora, János Lábár, Zsolt Fogarassy, Adél Rácz, Tatyana Kravchuk, and Michał A. Borysiewicz, “Multifactorial investiga-tions of the deposition process – material property relationships of ZnO:Al thin films deposited by magnetron sputtering in DC, pulsed DC and RF modes using different targets“ at the 49th International School & Conference on the Physics of Semiconductors “Jaszowiec 2021”, online, 1-10.09.2021 www.jaszowiec.edu.pl	Poster
Tatyana Kravchuk, Aleksandra Wójcicka, Zsolt Fogarassy, Adél Rácz, János Lábár, Ildikó Cora, and Michał A. Borysiewicz, “Understanding the room-temperature growth and deposition process of the transparent conducting oxide ZnO:Al thin films” at the 19th Israel Materials Engineering Conference (IMEC 2021), 13-14.12.2021 r. Jerusalem, https://www.imec2021.co.il/	Oral

Zsolt Fogarassy, Ildikó Cora, Csaba Dücső, Béla Pécz, Aleksandra Wójcicka, Michał A. Borysiewicz, Péter Németh, “Nanoszerkezetű 1-, 2-, 3-dimenziós anyagok (pásztázó) transzmissziós elektron-mikroszkópiája ((S)TEM)”, Seminar of the Vacuum Physics, Technology and Applications Group of the Hungarian Academy of Sciences and the Scientific Committee for Electronic Devices and Technologies of the Hungarian Academy of Sciences, 19.10.2021 r., Budapest	Seminar
Levchenko I., “Ohmic contacts to gallium nitride: Pd/Ni/Au”, VI IWC PAN Winter Workshop - KALATÓWKI, 24-29.04.2022	Oral
Schavion D., “Ge-doped GaN for strain-free cladding layers in lasers”, VI IWC PAN Winter Workshop - KALATÓWKI, 24-29.04.2022	Oral
Borysiewicz M., “Ohmic contact formation to wide nad gap materials”, OxyGaN Workshop 2022, 27.05.2022, Centre for Energy Research, Institute of Technical Physics and Materials Science, Budapest	Oral
Perlin P., “Nitrides semiconductors for optoelectronic applications: chances and challenges”, OxyGaN Workshop 2022, 27.05.2022, Centre for Energy Research, Institute of Technical Physics and Materials Science, Budapest	Oral
Grzanka S., “Lasers for quantum applications”, OxyGaN Workshop 2022, 27.05.2022, Centre for Energy Research, Institute of Technical Physics and Materials Science, Budapest	Oral
Wójcicka A., Fogarassy Z., Racz A., Dodony E., Kravchuk T., Borysiewicz M.: "Towards the Growth of UV-Transparent Conducting ZnMgO:Al Thin Films with Controllable Band-Gap Using Different Sputter Sources", 50th International School & Conference on the Physics of Semiconductors Jaszowiec 2022 (JASZ2022), Szczyrk 04-10.06.2022	Poster
Wójcicka A., Fogarassy Z., Kravchuk T., Kamińska E., Perlin P., Grzanka S., Borysiewicz M.: "Metal-GaN Junction Engineering for the Control of the Current-Voltage Characteristics of the Contacts", 50th International School & Conference on the Physics of Semiconductors Jaszowiec 2022 (JASZ2022), Szczyrk 04-10.06.2022	Poster

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