OXYGaN

Efficiency enhancement in GaN-based blue to blue-violet LDs by engineered nitride-oxide ohmic contacts

Y1 Newsletter—2020/2021

Project at a glance

OBJECTIVE

To overcome the difficulties in ohmic contact fabrication to GaN (laser diodes) LDs by introducing a novel contact scheme utilizing a bandgap engineered transparent conducting oxide (TCO) and interface engineering by appropriate GaN surface pre-treatment

WHY AZO?

A sustainable material, ZnO:Al (AZO) is a promising indium-free TCO for transparent contact applications. Through alloying with Mg, band gap engineering and refractive index tuning is possible to address desirable optical properties while maintaining low resistivity.

TECHNICAL OUTCOME

The technical goal of the proposal is to present a packaged LD demonstrator with improved efficiency using the new contacts.

GET IN TOUCH

WWW: oxygan.ite.waw.pl

Comments, business inquiries, future collaborators? We'd like to hear from you:
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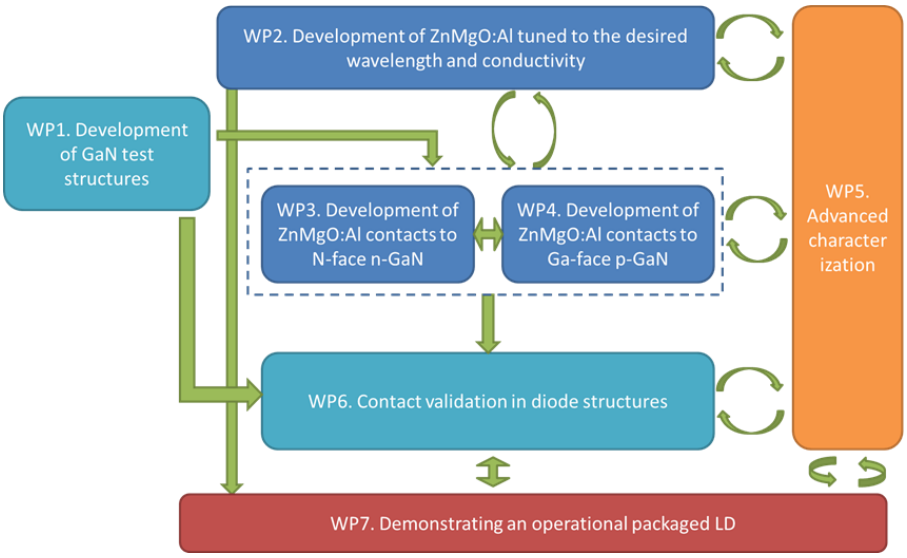
Project news

1st year of realization of the project

The project started on September 1, 2020. The work in the first year was focused mainly on the understanding of the deposition and growth processes of AZO and Mg-alloyed AZO transparent conducting films and testing their application in ohmic contacts to N-face n-GaN and Ga-face p-GaN. Particular attention is given to the processing challenges related to the different chemical and physical properties of N-face and Ga-face GaN surfaces.

In next year of this three-year project, we will want to continue the development of innovative ohmic contacts and integrate the developed solutions first into p-n GaN structures, and finally in full diode structures to demonstrate a packaged operational LD at the project end.



The 5 partners involved in the consortium are leaders in their respective fields and encompass a full value chain for material and LD research, development and manufacture as well as advanced characterization:

- Institute of Microelectronics and Photonics, Łukasiewicz Research Network (Łukasiewicz-IMiF, co-ordinator)
- Institute of High Pressure Physics, Polish Academy of Sciences (Unipress)
- Institute for Technical Physics and Materials Science, Centre for Energy Research (EK)
- Technion – Israel Institute of Technology (Technion)
- TopGaN Lasers inc. (TOP-GAN)

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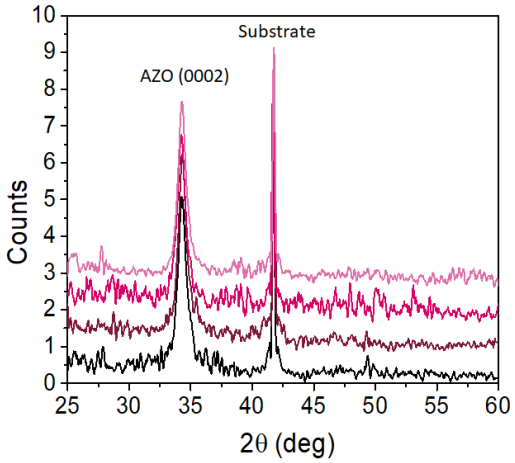
In-depth Studies on AZO deposition at Łukasiewicz – IMiF

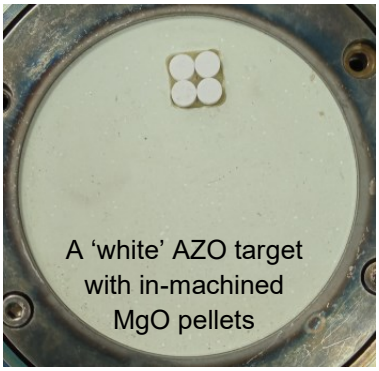
To form a solid basis for the development of Mg-alloyed AZO films, the researchers at Łukasiewicz—IMiF decided to take a very detailed look at how the AZO films grow, in particular how the various properties of sputter deposition processes of several AZO targets influence the transparency and conductivity of the AZO films. They did find the single process parameter which has the most influence on these values and obtained very low resistivity films with 1.2 mΩcm at very high crystalline quality (see patterns to the left). Such low values are usually achieved for AZO films deposited on heated substrates, however we found that when applying deposition with low target-to-substrate distance, the plasma bombardment adds enough energy to the films so that no heating is necessary. We also tackled the common dilemma of researchers trying to deposit AZO, i.e. some AZO targets are white, whereas some are black, with the same nominal composition—which one to use? The chemical composition and sputtering properties of both kinds of targets were analysed and it was found that although the starting material is different, no significant difference in the films was seen and any can be used for good quality results. The details of the findings have been submitted for publication in a Q1 journal.

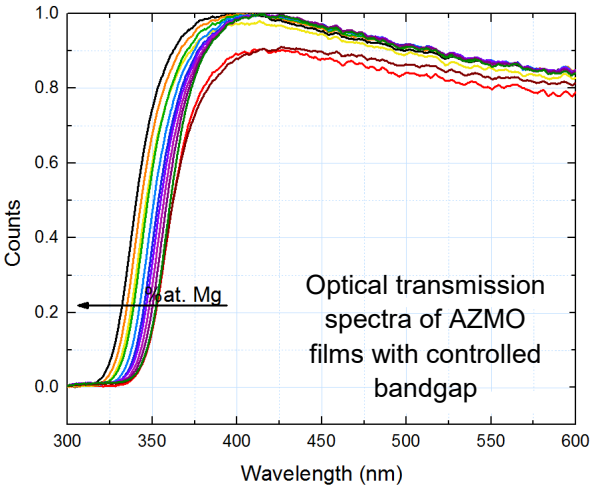

A 'black' AZO target. For a white one, see below



Overcoming pitfalls in Mg-alloyed AZO deposition

ZnMgO has been routinely demonstrated in the literature using epitaxial-grade growing techniques on matched substrates such as MBE. With sputtering, which is inherently an more energetic growth technique using different kinds of sources and the presence of gas in the chamber during sputtering, the development of substitutionally alloyed films is a challenge. Adding to that the controlled level of Al doping makes it even harder. Another hindrance is the need for low-temperature deposition due to the limited stability of the LD structure itself and the photolithographical patterning schemes used. The team at Łukasiewicz-IMiF tackled these challenges by applying a strategy of using different sputtering sources as well as of post-processing for the growth of high quality ZnMgO:Al (AZMO) films. They studied cosputtering from AZO and Mg targets, deposition from machined AZO+Mg and AZO+MgO targets (see photo) to get graded films in order to see what compositions are optimal and to order custom-made AZMO targets. They achieved controlled band-gap widening and high transparency for the deposited films (see diagram). Additionally, it was found that widening the band gap while maintaining low resistivity warrants additional changes to the target composition.


A 'white' AZO target with in-machined MgO pellets



Optical transmission spectra of AZMO films with controlled bandgap

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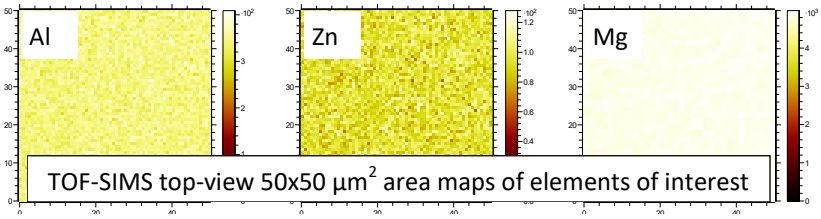
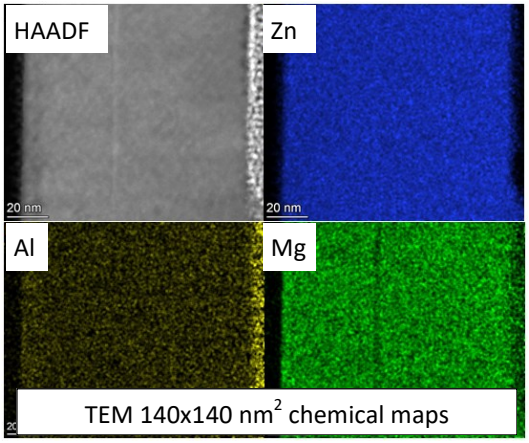
Advanced characterization at EK and Technion enables to understand and foresee

TOF-SIMS (Technion) as well as TEM microscopy with chemical mapping and XPS (EK) were applied to help in understanding the processes taking place in the samples at micro and nanoscale. Particularly in the Mg-containing material, where they were help understanding the Mg-incorporation process and enable to foresee how it will take place in next sample batches.



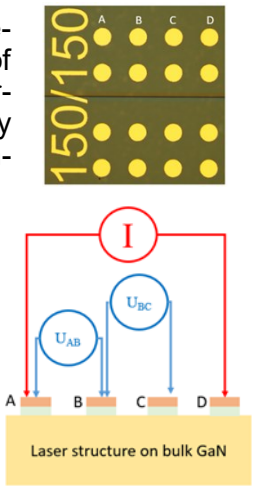
TOF-SIMS top-view 50x50 µm^2 area maps of elements of interest

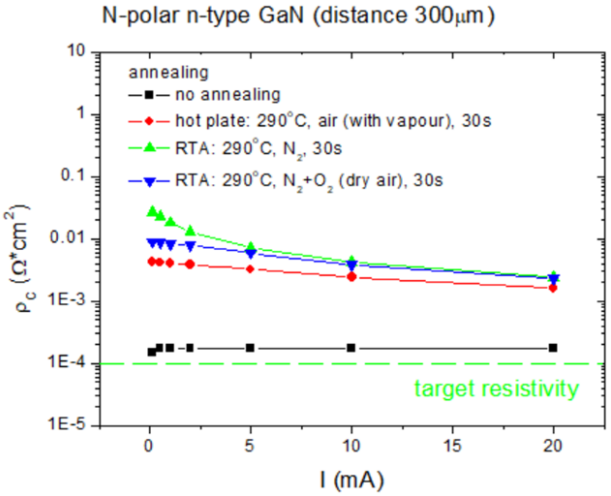


TEM 140x140 nm^2 chemical maps

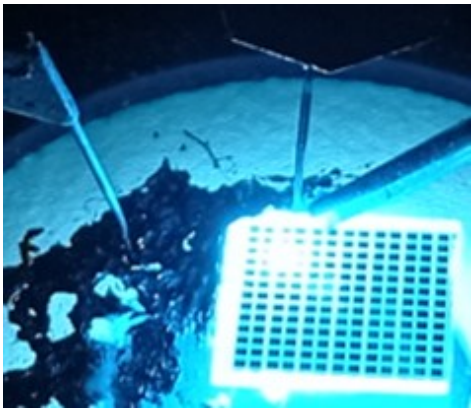
Electrical characterization of metal-bulk GaN contacts at Unipress

The team at Unipress adapted a measurement method for the exact determination of the contact resistance to N-polar n-GaN surface. They demonstrated very high quality ohmic metal contact to N-polar n-GaN. Contact resistance of no annealed (as deposited) Ti/Al/Ni/Au contact was at the range of 0.1 mΩcm, which is one of the best reported values for N-side contacts to n-GaN. We observed a slight degradation of this contact after annealing at temperature required for assembly laser chip to housing. It is now very important to obtain improved thermal stability of the contact to N-polar n-GaN.

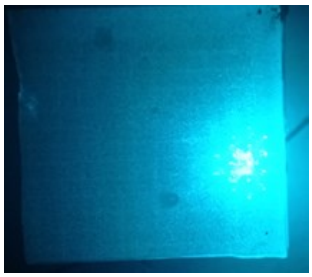




First light extracted from LDs with OxyGaN contacts at TOP-GAN



During the first year of the project, TOP-GAN team focused on demonstrating of possibility of using AZO layers fabricated at Łukasiewicz-IMiF as contact layers to p-type GaN structures. As the first task we decided to use AZO layer as a contact, transparent layer to a standard TOP-GAN laser structure. We wanted to verify, if we can form the AZO contacts without damaging the InGaN quantum wells, and also if it is possible to inject the current in homogeneous way to the laser diode structure. The images below show a processed GaN-laser/AZO/Au structure with a 300x300 mm contact. It was possible to inject the current to the structure, although the operating voltage was quite high (9-10V at 100mA). The position of the peak of the emitted spectrum initially indicates no damage to the epitaxial structure, being promising for further steps.



The photographs show the laser structure as seen from the top (left) and substrate side (right).

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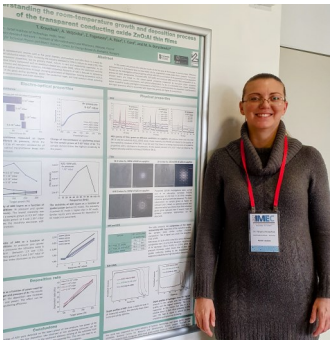
Dissemination of project results

The results obtained within the frames of the project were disseminated in several conference presentations, including:

- 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“ at the 49th International School & Conference on the Physics of Semiconductors "Jaszowiec 2021" (on-line)
- 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)



Dr. Kravchuk with the OxyGaN poster at the IMEC conference

Selected results were included in the following seminar

- Zsolt Fogarassy, Ildikó Cora, Csaba Dücső, Béla Pécz, Aleksandra Wójcicka, Michał A. Borysiewicz, Péter Németh, “Nanoszerkezetű 1-, 2-, 3-dimenziós anyagok (pásztázó) transzmissziós elektronmikroszkópiája ((S)TEM)” given at 19.10.2021 at the 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

The following publication has been submitted for review to a Q1 journal:

- Aleksandra Wójcicka, 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 pulsed DC, DC and RF modes using different targets”

Project website is online

2021 Dissemination of results

2021 was a tough year in terms of conference participation with most of the meetings being postponed or cancelled altogether. The OxyGaN team also had to postpone the participation in the International Conference on Reactive Sputter Deposition 2021, but have successfully participated in several on-line or in person meetings including:

- 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”** (on-line)

Jaszowiec School & Conference

IMEC2021

The OxyGaN project website is online at www.oxygan.ite.waw.pl with the details on project ambition and goals, the consortium and funding bodies available.

The publications and other information materials will be available and updated during the run of the project.

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