Ioffe Institute
Politekhnicheskaya 26, 194021, St Petersburg, Russia
Phone: +7 (812) 297-2245 • Fax: +7 (812) 297-1017 • E-mail: post@mail.ioffe.ru • http://www.ioffe.ru

# Scientific and Engineering Groundwork for R&D of Efficient AlInGaN Chips for High-power and High-voltage White LEDs and Their Business Proposals

*L. K. Markov*

l.markov@mail.ioffe.ru

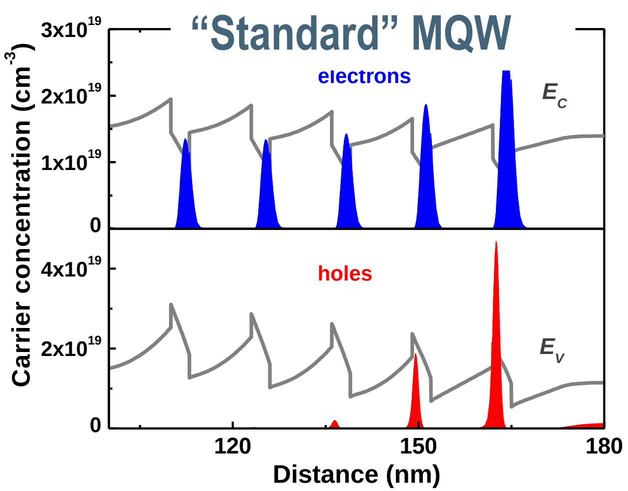
# Fields of Expertise (2000-2017)

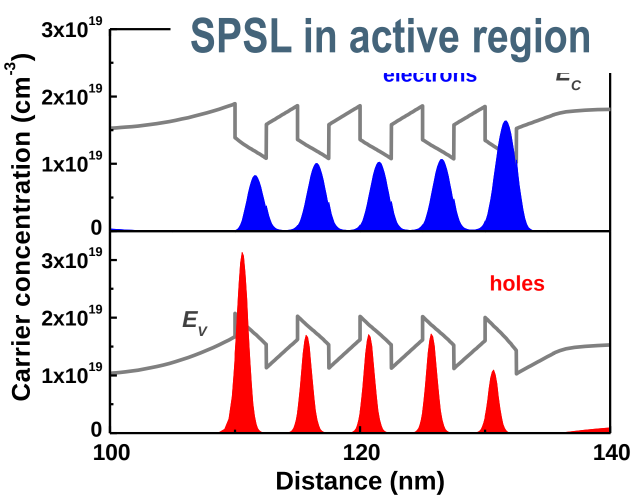
## Main focus:

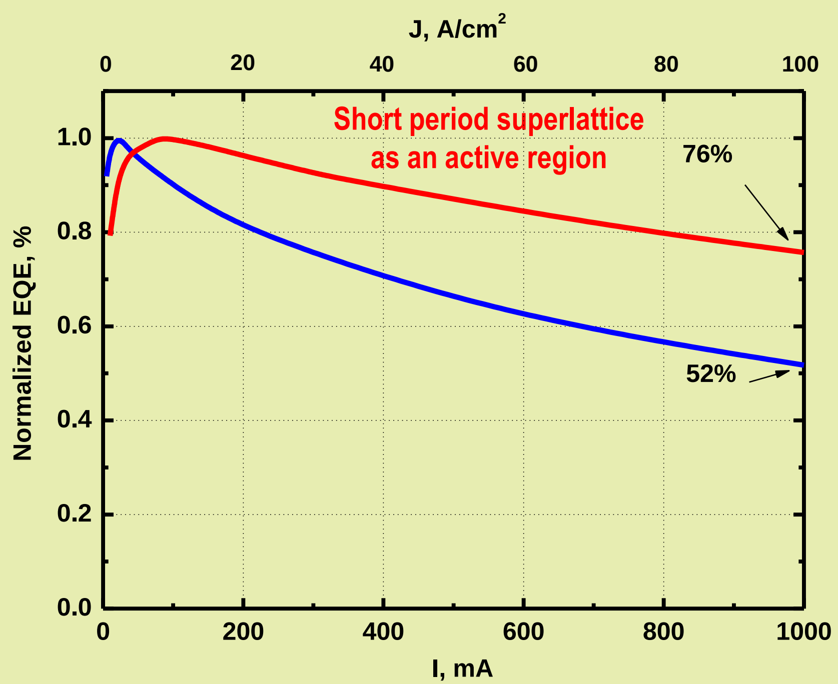
- *Reduction of the efficiency droop by an appropriate MQW design*
- *Simulation of physical phenomena crucial for LED operation*
- *Substrate lift-off and texturing the back surface of n-contact layer*
- *Advanced ITO deposition technology developed for antireflection coating*
- *Vertical LED fabrication*
- *Multilayer metallization for flip-chip LEDs*
- *HV LEDs based on flip-chip design*

# Reduction of the Efficiency Droop by an Appropriate MQW Design

## Carrier concentration distributions



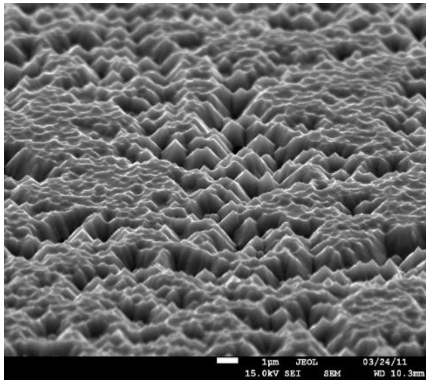



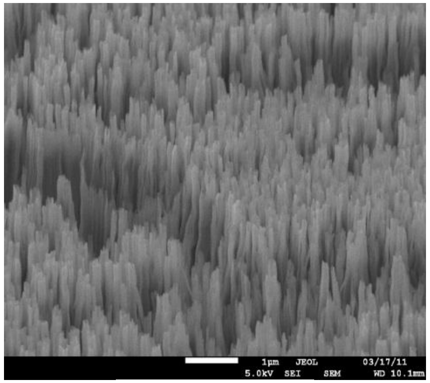

The droop in SPSL structure is two times smaller than in "standard" MQW one

# Texturing the Back Surface of the N-contact Layer

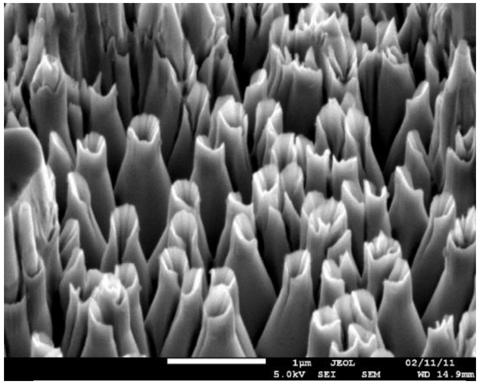
**Different types of relief gained by treatment variation for optimal light extraction**



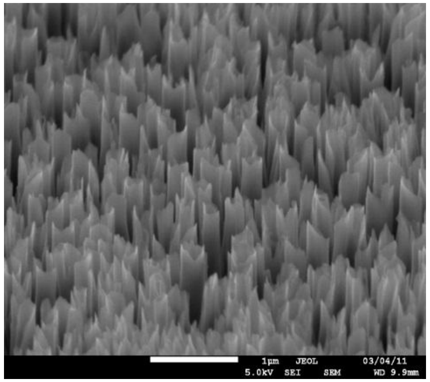

Ar:$BCl_3$



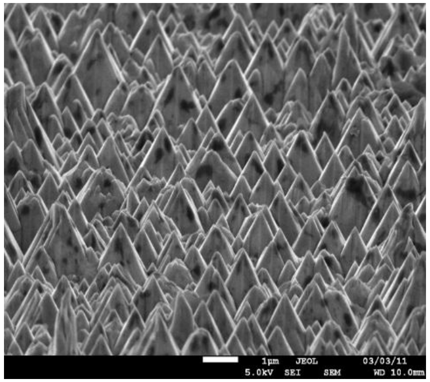

Ar:$Cl_2$



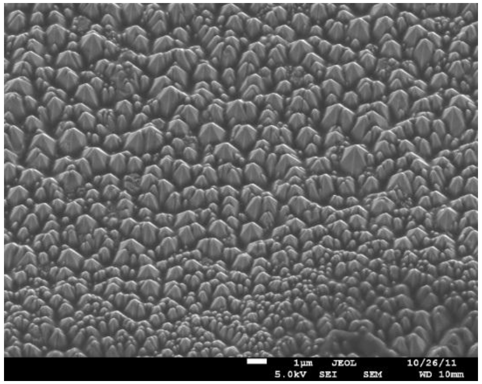

KOH +Ar:$Cl_2$:$BCl_3$




Ar:$Cl_2$:$BCl_3$

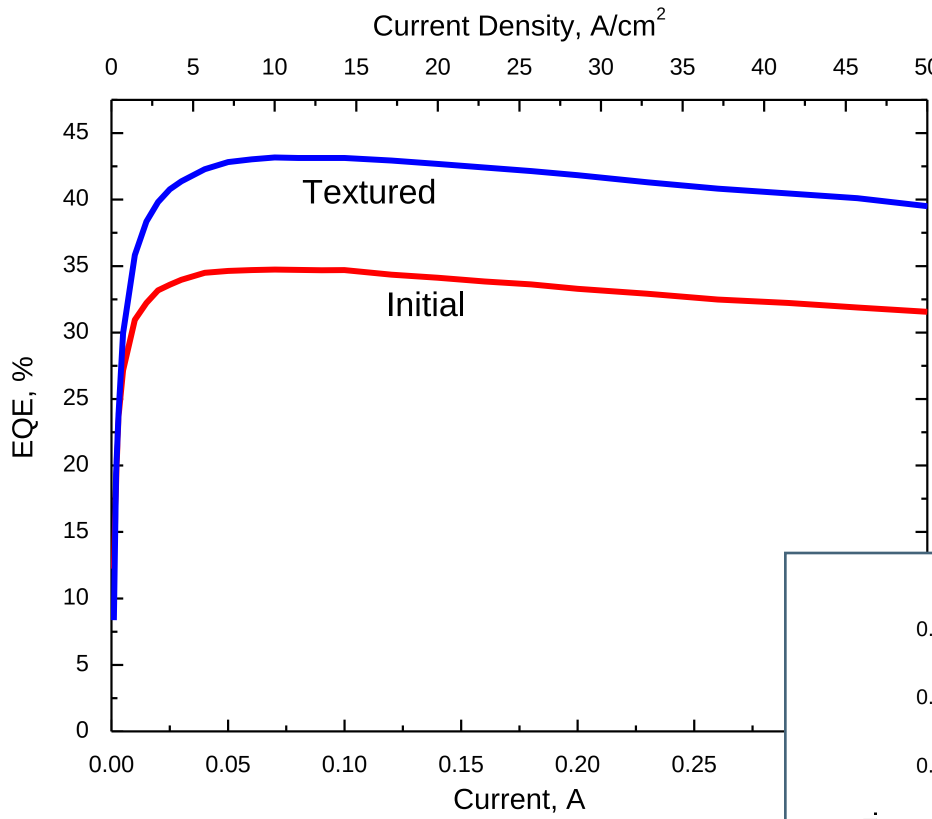



KOH

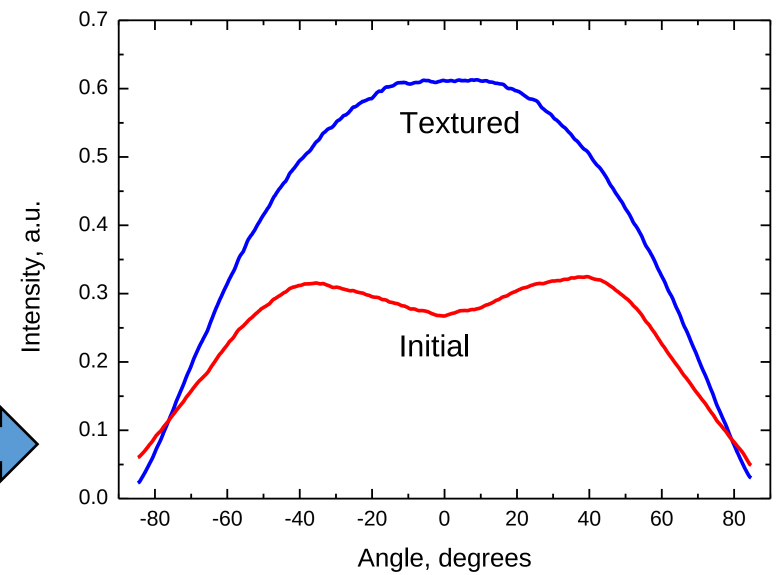



Ar:$Cl_2$:$BCl_3$+KOH

# Effects of Texturing

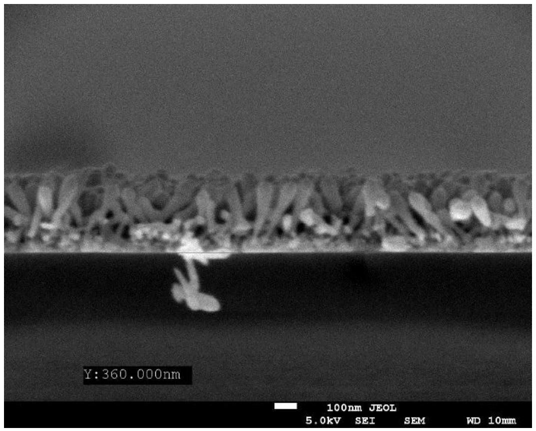



Increase in light extraction efficiency results in up to 30% improvement in integral EQE

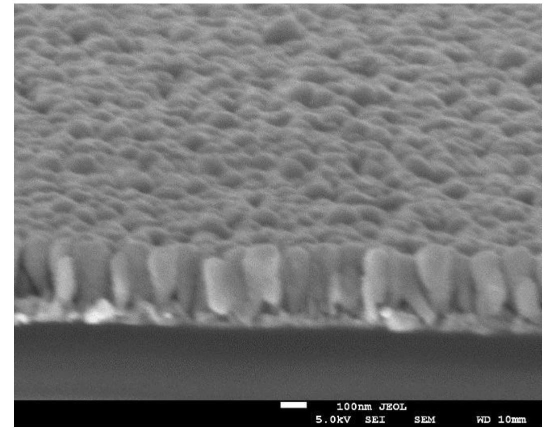



Effective light scattering at textured surface modifies LED radiation pattern

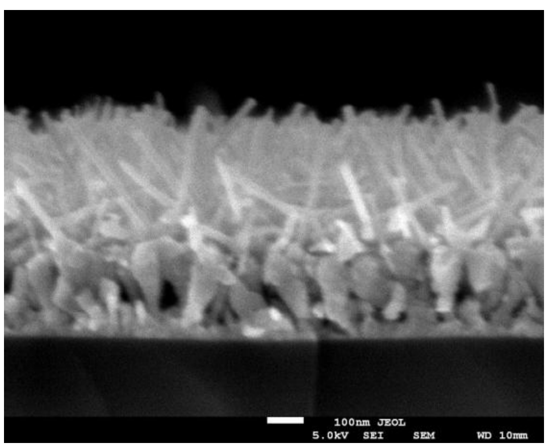
# The Method For ITO Layer Refractive Index Variation



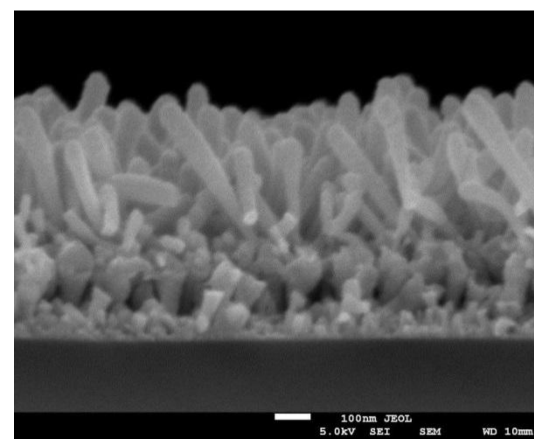

The method allows one to deposit ITO films with different refractive indices in the range 1.2 – 2.0
Gradient index films




Antireflection coatings



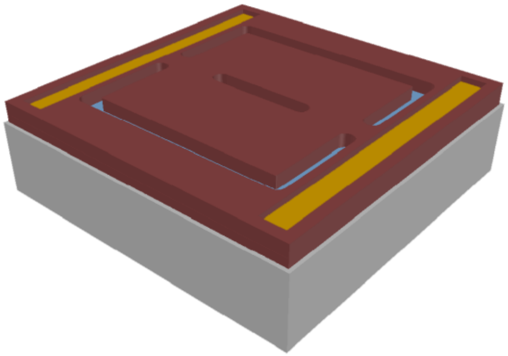

Multilayer coatings deposited within this approach

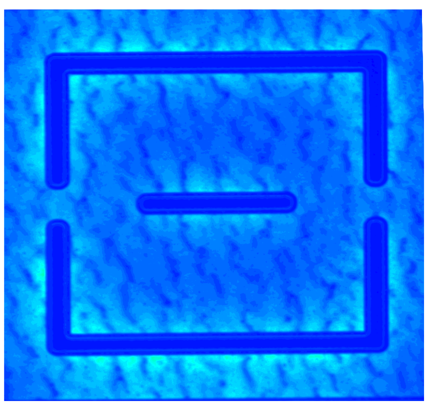



Conducting Bragg reflectors

Patent pending

# Multilayer Metallization Flip-chip LEDs





Chip linear size: 1.28 mm  (45 mil)
Active (p-n junction) area: 1.00 mm$^2$
Active to total area ratio: 78%

**Flip-chip design** provides:

- ✓ Lowest thermal resistance between the die and the heat sink;
- ✓ Increasing the quantum efficiency due to high reflective ITO-based p-contact and reflective n-contact;
- ✓ Possibility of operating at higher currents.

**Multilayer plating mirror** allows:

- ✓ To minimize the light absorption;
- ✓ To minimize the thermal resistance of the chip due to the direct contact with the heat sink;
- ✓ To minimize chip area due to the delivery of current to n-contact via the second layer metallization.

**Calculative optimization of the chip design** provides:

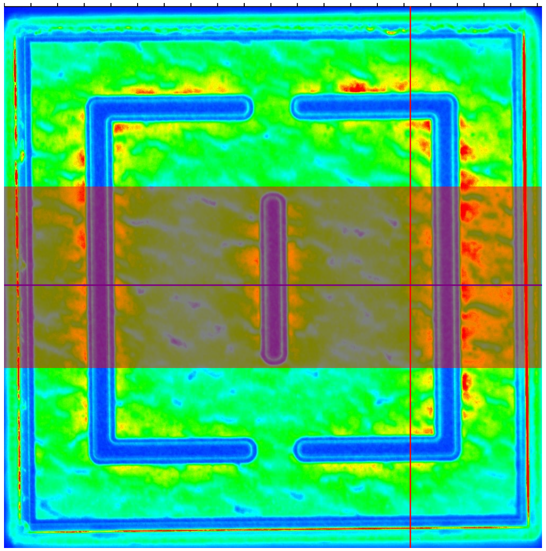
- ✓ Optimal current spreading in the active region;
- ✓ Minimum series resistance;
- ✓ The optimal active region area to the total area ratio.

# Experimental Near Field Emission and Simulated Pumping Current Density

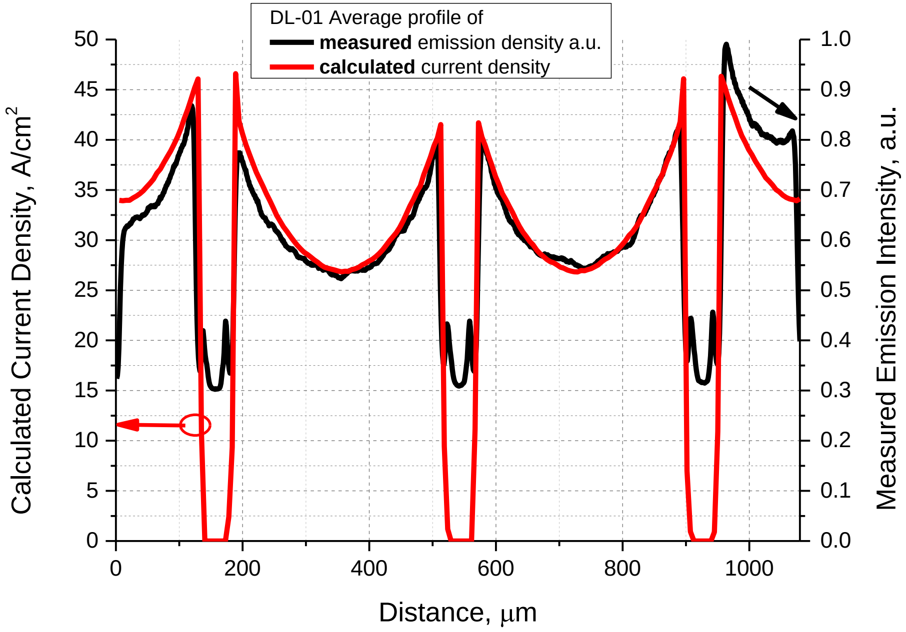
## Chip electrical parameters:

$R_{diff} \approx 0.27\ \Omega$   $\langle J \rangle = 35\ A/cm^2$   $\sigma_J \approx 7\ A/cm^2$  @ 350 mA

### Near field emission (experimental)

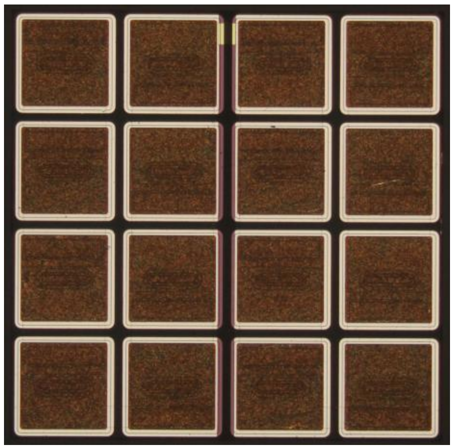


### Data averaged over the stripe shown on left figure




**Standard current density deviation for this chip is about 20% , that means rather uniform current spreading and ability to operate at higher currents**

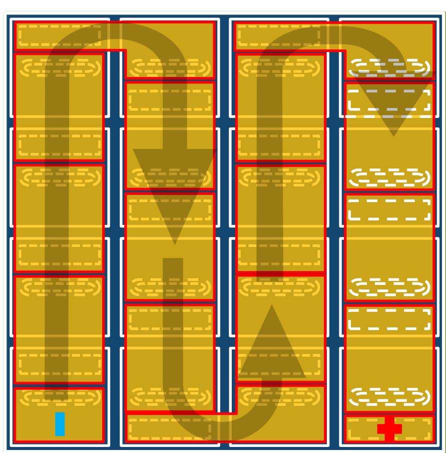
# Integrated High-voltage Flip-chip Design



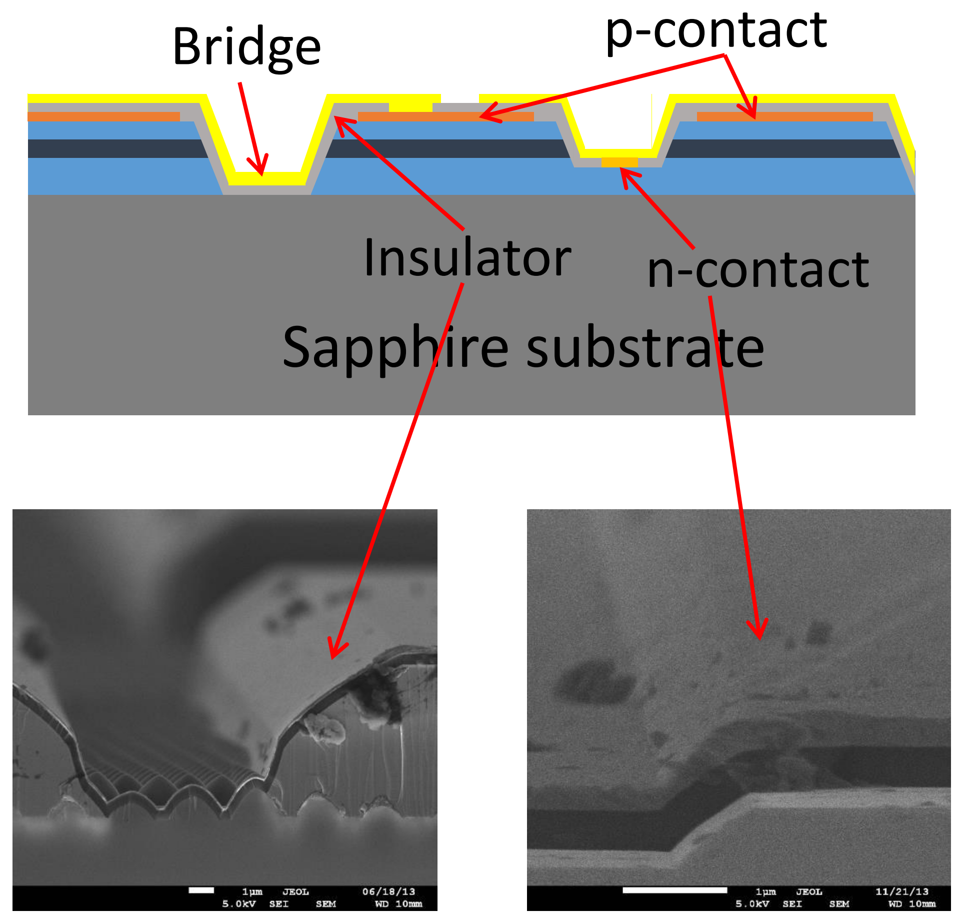
16 elements connected in series

Operating voltage: ~48-50V

Chip size: 45 mil (1145 µm)



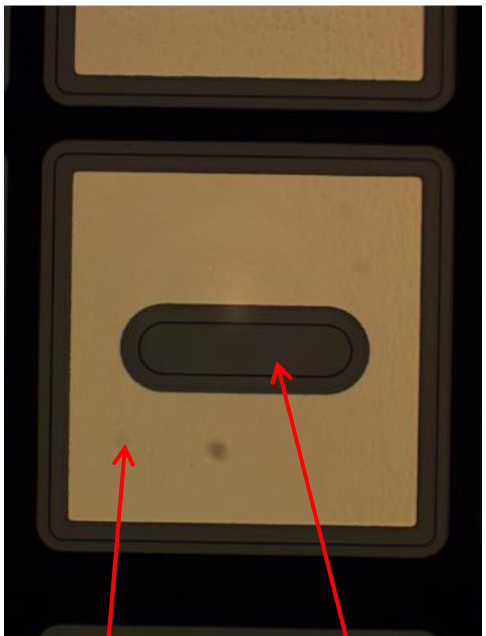
Schematic image




Flip-chip design makes it possible to benefit all the advantages described above

# Some Steps of High-voltage Chip Processing

**After mesa etching and p-contact deposition**



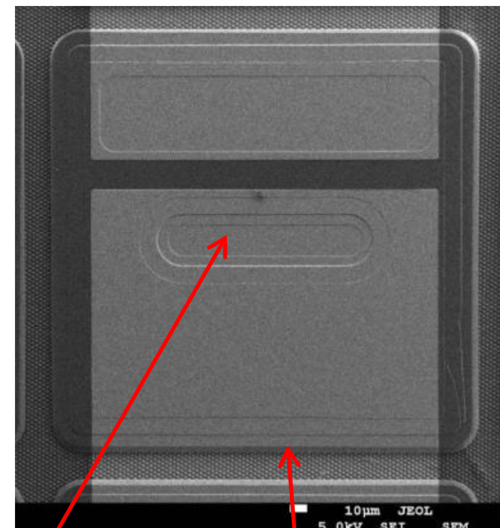
p-contact

n-GaN surface

**After insulation deposition**

$SiO_2$

**After n-contact and interconnecting metal layer deposition**



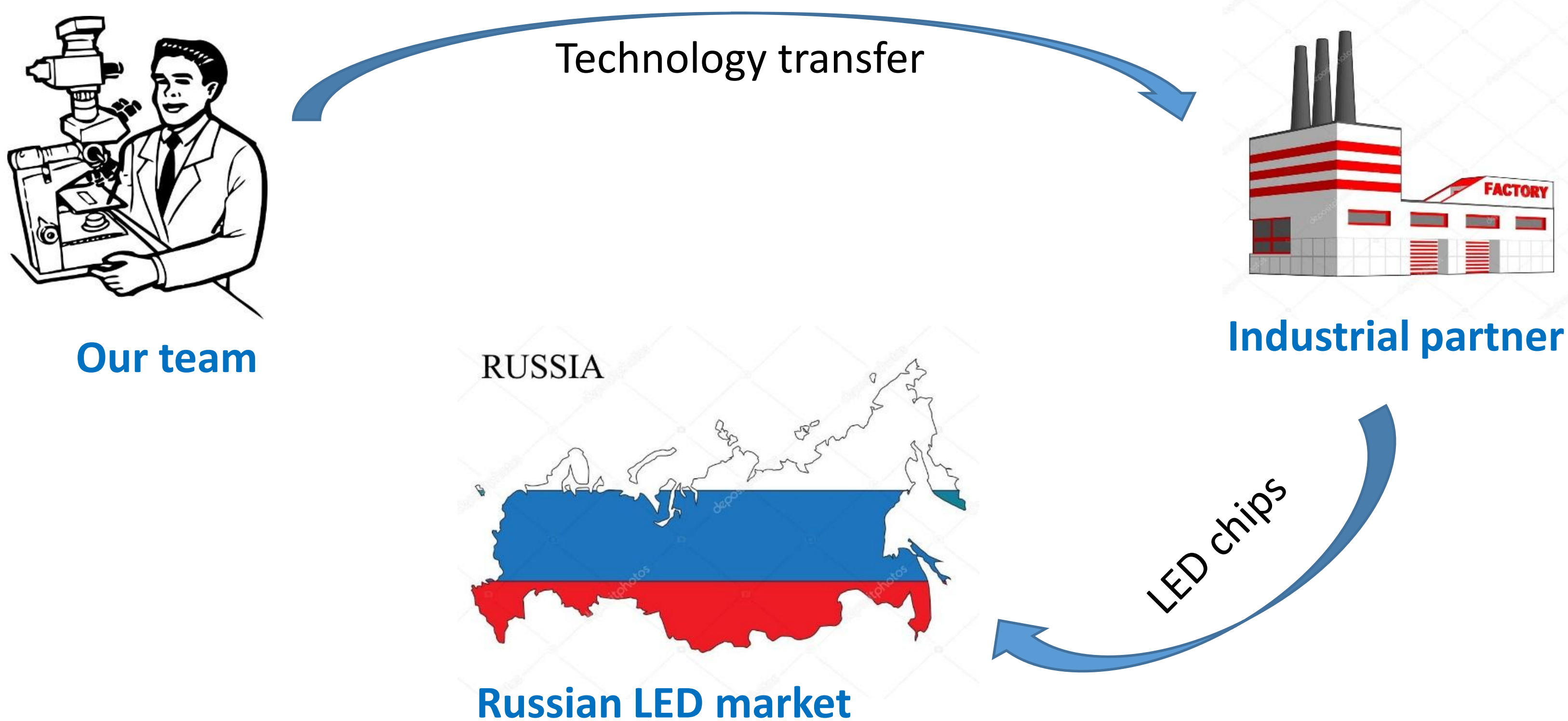

n-contact

Interconnecting metal bridge

# Business Proposals

**We are in a search for experienced industrial partners who are interested in their product line shift to effective high power LEDs.**

## Probable scheme of collaboration



# Mutually Beneficial Collaboration

## For the partner side

- ✓ Adoption of new technology approaches
- ✓ Improvement of LED power
- ✓ Increase of LED efficiency
- ✓ Market expansion

## For our team side

- ✓ Technology promotion
- ✓ Getting feedback from industrial partner and adjusting technology approaches according to it's needs
- ✓ Further technology development

# List of principal Publications


1) Zakheim D.A., Smirnova I.P., Arakcheeva E.M., Kulagina M.M., Gurevich S.A., Rozhansky I.V., Lundin V.W., Tsatsulnikov A.F., Sakharov A.V., Fomin A.V., Zakheim A.L., Vasil`eva E.D., Itkinson G.V. Fabrication of high-power flip-chip blue and white LEDs operating under high current density. Phys. Status Solidi C-Conf. 2004, v.1, **10**, 2401-2404
2) Zabelin V. Zakheim D.A., Gurevich S.A. Efficiency improvement of AlGaInN LEDs advanced by ray-tracing analysis. 2004, IEEE J. Quantum Electron., v.**40**, 12, 1675-1686
3) Zakheim D.A., Smirnova I.P., Rozhanskii I.V., Gurevich S.A., Kulagina M.M., Arakcheeva E.M., Onushkin G.A., Zakheim A.L., Vasil`eva E.D., Itkinson G.V. High-power flip-chip blue light-emitting diodes based on AlGaInN. 2005, Semiconductors, v.**39**, 7 851-855
4) Malyutenko V.K., Malyutenko O.Y., Zinovchuk A.V., Zakheim A.L., Zakheim D.A., Smirnova I.P., Gurevich S.A. Remote temperature mapping of high-power InGaN/GaN MQW flip-chip design LEDs. 2005, Proc. SPIE, v.**5840**, 884
5) Rozhansky I.V., Zakheim D.A. Analysis of dependence of electroluminescence efficiency of AlInGaN LED heterostructures on pumping. 2005, Phys. Status Solidi C Curr. Top. Solid State Phys., v.**3**, 2160-2164
6) Rozhansky I.V., Zakheim D.A. Analysis of the causes of the decrease in the electroluminescence efficiency of AlGaInN light-emitting-diode heterostructures at high pumping density, 2006, Semiconductors, v.**40**, 7, 839-845
7) Onushkin G.A., Zakgeim A.L., Zakgeim D.A., Rozhansky I.V., Tsatsulnikov A.F., Lundin W.V., Sizov D.S. Micro-EL studying of high power blue LEDs. 2006, Phys. Status Solidi C Curr. Top. Solid State Phys., v.**3**, 2149-2152
8) Smirnova I.P., Markov L.K., Zakheim D.A., Arakcheeva E.M., Rymalis M.R. Blue flip-chip AlGaInN LEDs with removed sapphire substrate. 2006, Semiconductors, v.**40**, 11, 1363-1367
9) Rozhansky I.V., Zakheim D.A. Analysis of processes limiting quantum efficiency of AlGaInN LEDs at high pumping. 2007, Phys. Status Solidi A-Appl. Mat., v.**204**, 1, 227-230
10) Seisyan R.P., Ermakova A.V., Kaliteevskaya N.A., Markov L.K., Rymalis M.R. Thin epitaxial GaN films ablated by a pulsed KrF excimer laser. 2007, Tech. Phys. Lett., v.**33**, 4, 302-304
11) Pavluchenko A.S., Rozhansky I.V., Zakheim D.A. Manifestation of the injection mechanism of efficiency droop in the temperature dependence of the external quantum efficiency of AlInGaN-based light-emitting diodes. 2009, Semiconductors, v.**43**, 10, 1351-1355
12) Markov L.K., Smirnova I.P., Pavlyuchenko A.S., Arakcheeva E.M., Kulagina M.M. Reflecting p-contact based on thin ITO films for AlGaInN flip-chip LEDs. 2009, Semiconductors, v.**43**, 11, 1521-1525
13) Smirnova I.P., Markov L.K., Arakcheeva E.M., Pavluchenko A.S., Zakgeim D.A., Kulagina M.M. Raising the quantum efficiency of AlGaInN flip-chip LEDs by Reactive ion etching of the outer side of SiC substrates. 2010, Semiconductors, v.**44**, 5, 657-660
14) Zakheim D.A., Pavluchenko A.S., Bauman D.A. Blue LEDs – way to overcome efficiency droop. 2011, Phys. Status Solidi C Curr. Top. Solid State Phys., v.**8**, 7-8, 2340-2344
15) Efficiency droop suppression in InGaN-based blue LEDs: Experiment and numerical modelling
Zakheim D.A., Pavluchenko A.S., Bauman D.A., Bulashevich K.A., Khokhlev O.V., Karpov S.Y. 2012, Phys. Status Solidi A-Appl. Mat., v.**209**, 3 456-460

# List of principal Publications (cont.)

16) Smirnova I.P., Markov L.K., Pavlyuchenko A.S., Kukushkin M.V. AlGaInN-based light emitting diodes with a transparent p-contact based on thin ITO films.2012, Semiconductors, v.**46**, 3, 369-373
17) Markov L.K., Smirnova I.P., Pavlyuchenko A.S., Kukushkin M.V., Vasil`eva E.D., Chernyakov A.E., Usikov A.S. Comparison of the properties of AlGaInN light-emitting diode chips of vertical and flip-chip design using silicon as the a submount. 2013, Semiconductors, v.**47**, 3, 409-414
18) Smirnova I.P., Markov L.K., Pavlyuchenko A.S., Kukushkin M.V., Pavlov S.I. Optimization of the deposition technique of thin ITO films used as transparent conducting contacts for blue and near-UV LEDs. 2014, Semiconductors, v.**48**, 1, 58-62
19) Zakheim D.A., Itkinson G.V., Kukushkin M.V., Markov L.K., Osipov O.V., Pavlyuchenko A.S., Smirnova I.P., Chernyakov A.E., Bauman D.A. High-power AlGaInN LED chips with two-level metallization. 2014, Semiconductors, v.**48**, 9, 1254-1259
20) Markov L.K., Smirnova I.P., Pavluchenko A.S., Kukushkin M.V., Zakheim D.A., Pavlov S.I. Use of double-layer ITO films in reflective contacts for blue and near-UV LEDs. 2014, Semiconductors, v.**48**, 12, 1674-1679
21) D. A. Zakheim, G. V. Itkinson, M. V. Kukushkin, L. K. Markov, O. V. Osipov, A. S. Pavluchenko, I. P. Smirnova, and D. A. Bauman. High power blue AlGaInN LED chips with two-level metallization. Phys. Status Solidi C **12**, No. 4–5, 381–384 (2015)
22) Pavluchenko A.S., Markov L.K., Smirnova I.P., Zakheim D.A. Calculation of the optimal architecture of a double-layer ITO film intended for use in reflective contacts in blue and near-UV LEDs. 2015, Semiconductors, v.**49**, 7, 972-975
23) Markov L.K., Smirnova I.P., Pavluchenko A.S., Kukushkin M.V., Zakheim D.A., Pavlov S.I. Technique for forming ITO films with a controlled refractive index. 2016, Semiconductors, v.**50**, 7, 984-988

## Main patents numbers

- RU 2 231 171 C1 LIGHT-EMITTING DIODE
- RU 2 247 444 C1 HEAVY-POWER LIGHT-EMITTING DIODE
- RU 2 306 634 C1 LIGHT-EMITTING SEMICONDUCTOR HETEROSTRUCTURE
- RU 2 530 487 C1 METHOD OF PRODUCING NITRIDE LIGHT-EMITTING DIODE
- RU 2 549 335 C1 LIGHT-EMITTING DIODE
- RU 2 570 060 C1 HIGH-VOLTAGE LIGHT-EMITTING DEVICE