MSE Day 2022 Karlsruhe

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Tuning III-nitride nano-LEDs via laser-micro-annealing

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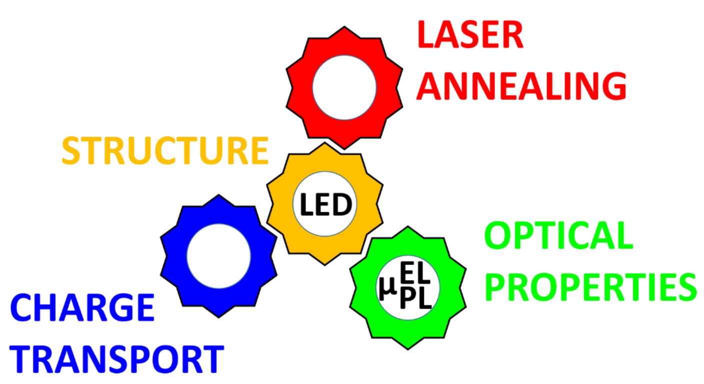
CORRELATIVE METHODS



MOTIVATION

NANO-LEDS: III-NITRIDES

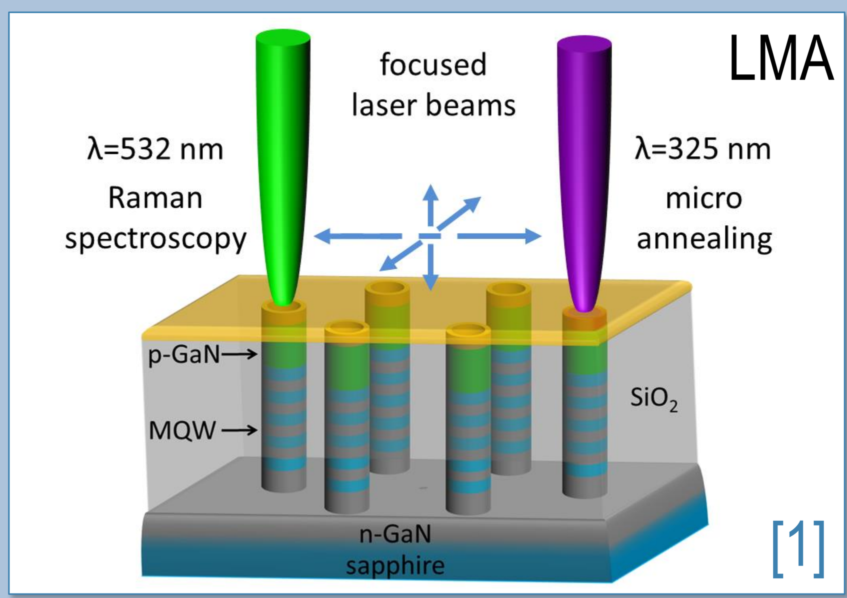
- tunable wavelength emission
  - → useful for chemical reactions
  - → useful for electro-optic pumping
- long term stability, reliability
- chemical inertness
  - → structure definition by dry etching

Tasks:
develop single nano-LED fabrication
- dry etching methods, etching procedure?
- suppression of non-rad. recombination [1]?

monitor optical characteristics
use laser to condition nano-LEDs
↓
Laser–Micro-Annealing [1]

LASER-MICRO-ANNEALING (LMA): REQUIREMENTS

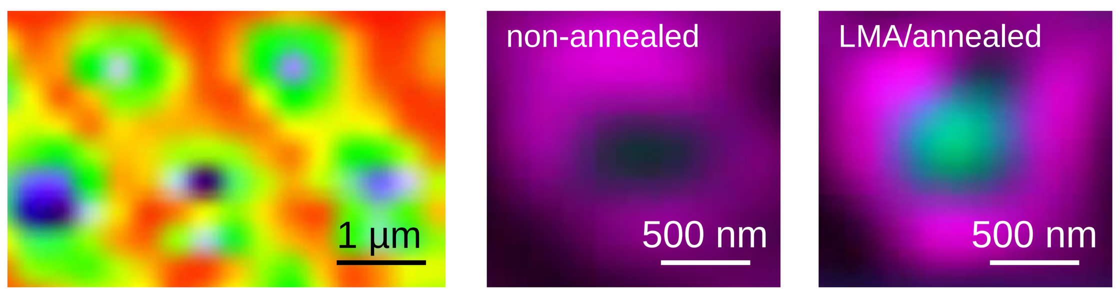
- laser source: suitable wavelength, tunable output power, stability
- laser spot: adjustable laser spot size down to 500 nm
- sample positioning



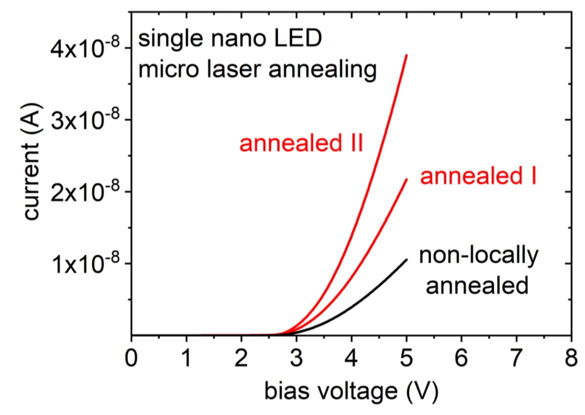
ADVANTAGES

- local annealing/conditioning possible
- tunable (input power and time) process
- "fast" process → suitable for mass production

LASER-MICRO-ANNEALING



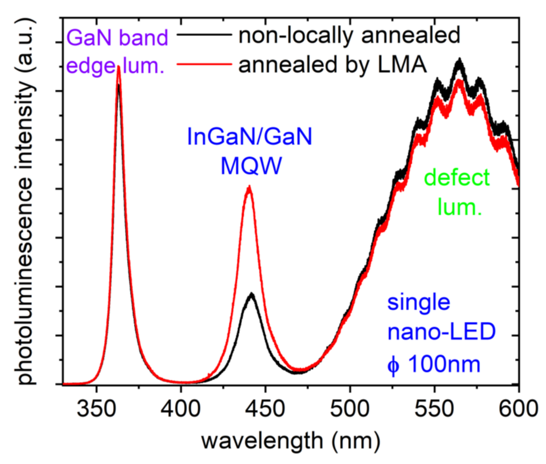
- "nano" PL mapping regime: detail of intensity distribution from the single nano-LEDs in array. Etching process responsible for suppression of radiative recombination in central- MQW region
- non-annealed vs. annealed nano-LEDs: significant increase in photoluminescence intensity from central region of single nano-LED. Tuning of laser micro annealing process to condition individual nano-LED structures possible

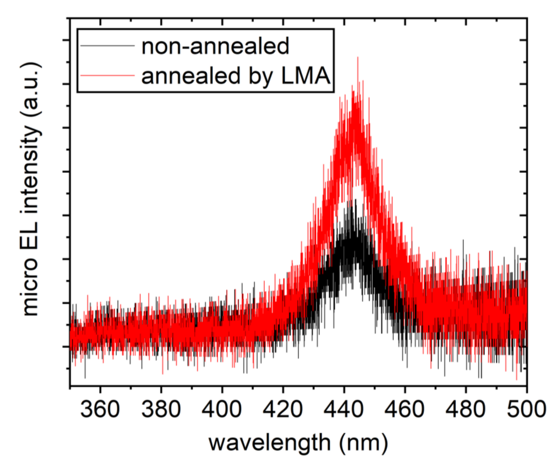


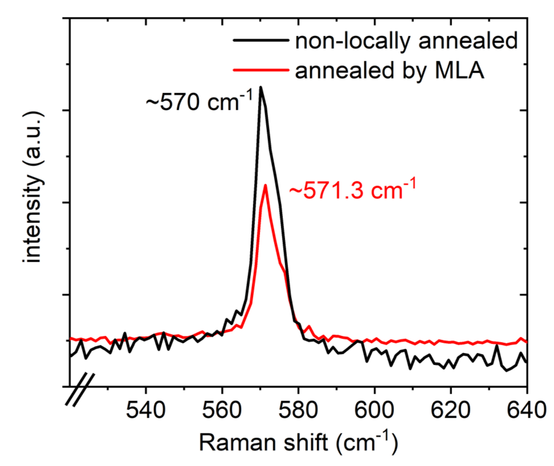
- significant ohmic contact improvement: about 4 x higher currents at 4V bias voltage

nano-LEDs after local micro laser annealing → suppression of non-radiative recombination
increase of PL emission intensity & higher work current / improvement of ohmic contacts

LMA conditioning: useful tool for the compensation of technological / etching effects





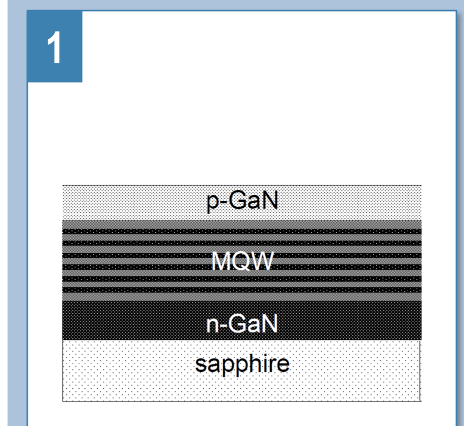


LMA conditioning: significant PL (in blue region) and EL intensity increase
Raman shift E_2^H mode increases → LED work temperature reduced by ~ 60K

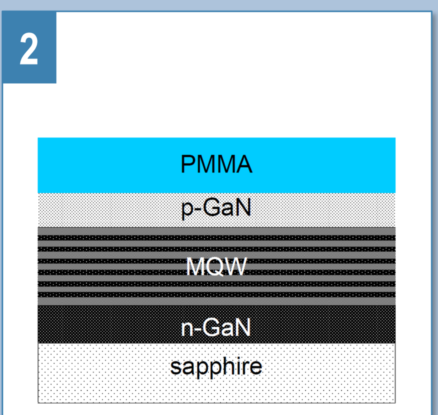
SAMPLE PREPARATION

structure definition / formation:
p-GaN/MQW/n-GaN based nano-LEDs

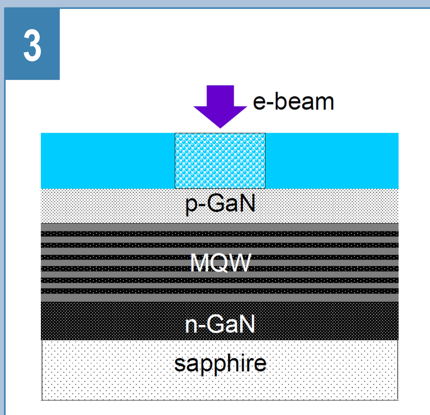
Schematic outline of nano-LED processing [2,3]



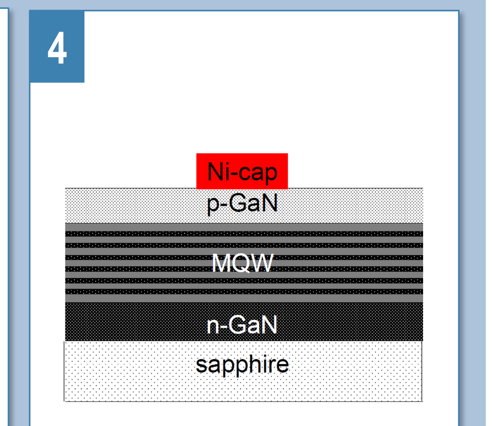
- conventional MOVPE LED layer system



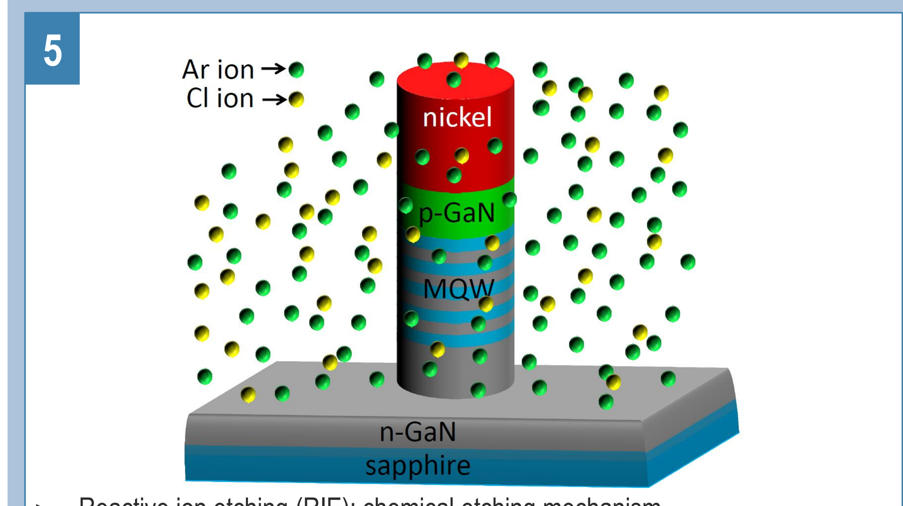
- PMMA – e-beam photoresist
- "soft" bake



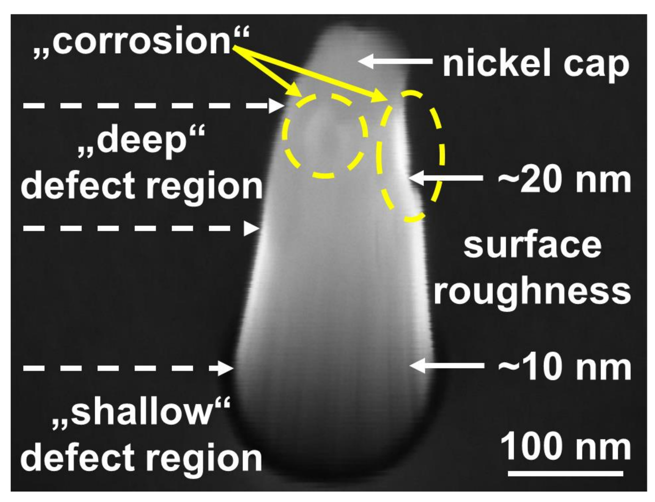
- e-beam lithography
- developing



- Ni cap metallization
- lift-off

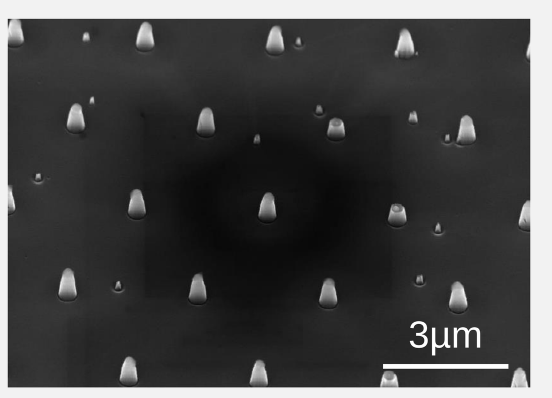


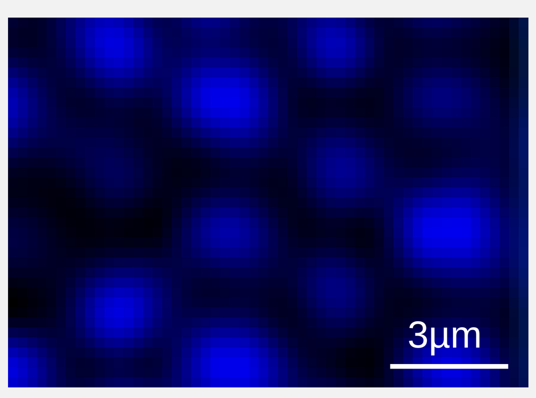
- Reactive ion etching (RIE): chemical etching mechanism

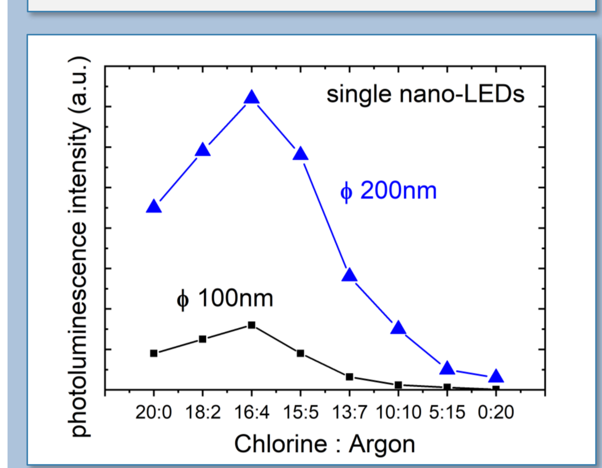


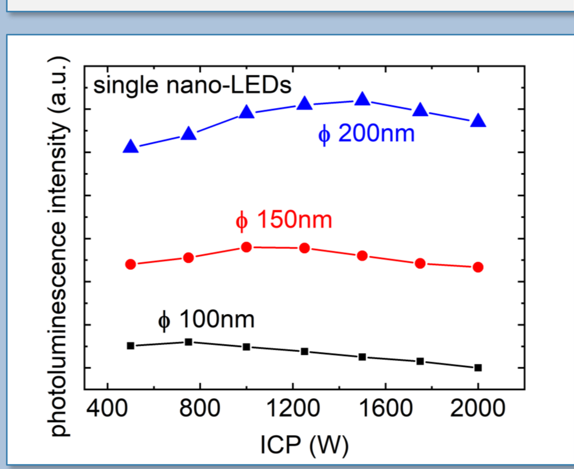
micro PL intensity decreases as a result of MQW "corrosion" → degradation of optical properties

RIE process vs. micro-photoluminescence (µ-PL) measurements







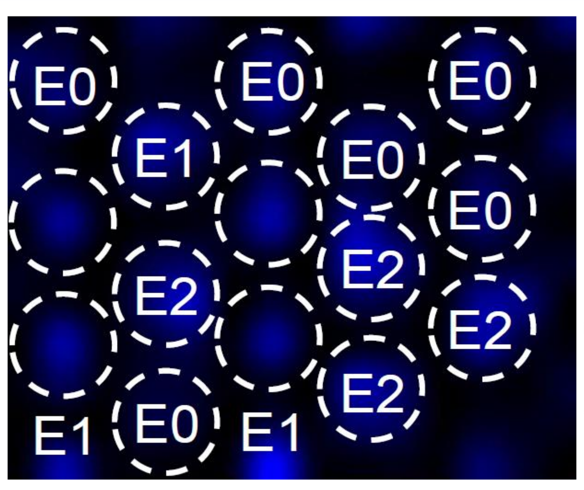


- lateral mapping of micro PL intensity (at 445 nm → emission maximum in PL spectra) from the nano-LED array performed at room temperature
- non-uniform PL intensity from single nano-LED structures observed over a large area after RIE process
- instable - strong influence of Cl_2/Ar gas etching mixture on PL intensity. Ratio correlates with influence of chemical versus physical etching in RIE [4]
- micro PL intensity as a function of RIE inductively coupled plasma (ICP) power. Optimal ICP power increases with nano-LED diameter

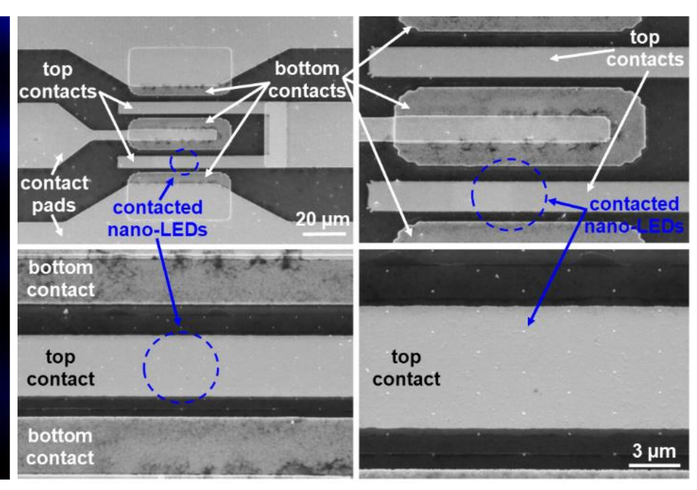
PL intensity strongly affected by etching conditions

TUNING / CONDITIONING PROCEDURE

Conditioning of optical properties → nano-LED driven electro-optic convertor [7]

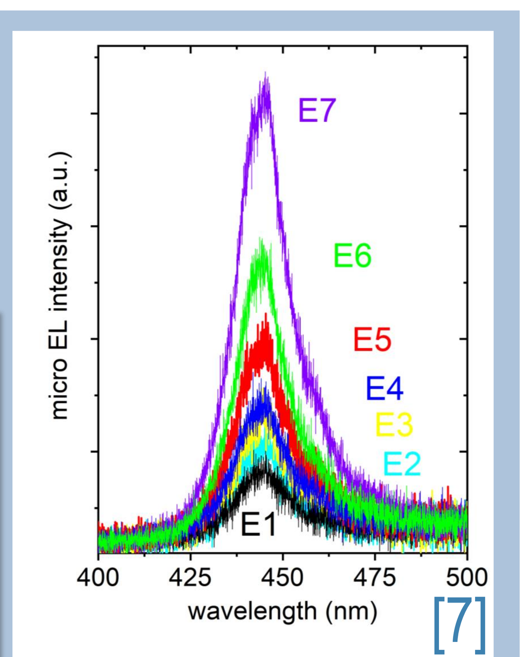


Micro- EL mapping performed on nano-LEDs (with a peak wavelength emission centered at ~ 445 nm) in an array with three different annealing conditions: non-locally annealed E0 and locally E1 and E2 annealed [1]. The LEDs´ EL intensity becomes higher according to the LMA process carried out.

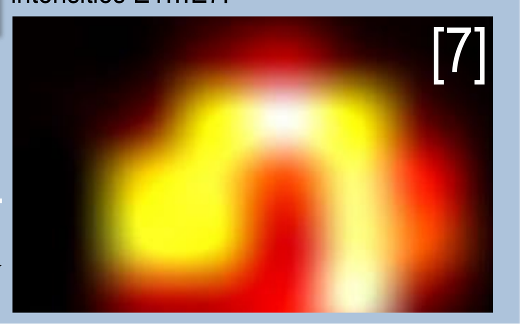


Fully integrated nano-LED structures in a device layout suitable for DC and HF characterization. This testing platform could serve as a part for electro-optic convertors in transmistior [5,6] based optical computing units.

Micro Raman mapping with different states of phase change in the $Ge_2Sb_2Te_4$ nano-membrane initialized locally by nano-LED optical pulses. →



Micro- EL measurements performed on nano-LEDs in an array with seven different intensities E1…E7.



CONCLUSIONS

IMPORTANT TECHNOLOGICAL STEPS DEVELOPED

- nano-LED fabrication process: etching process responsible for suppression of radiative recombination in central- MQW region
- local laser micro annealing (LMA) process: tuning nano-LED´s optical properties demonstrated
- Raman spectroscopy studies reveal that the optical pulses emitted from the nano-LEDs initialize locally substantial changes in nano-membrane phase state

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[7] M. Mikulics et al., to be published in FlatChem.