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Selective area micromachining of InGaN/GaN LED chips using ultrashort pulse laser

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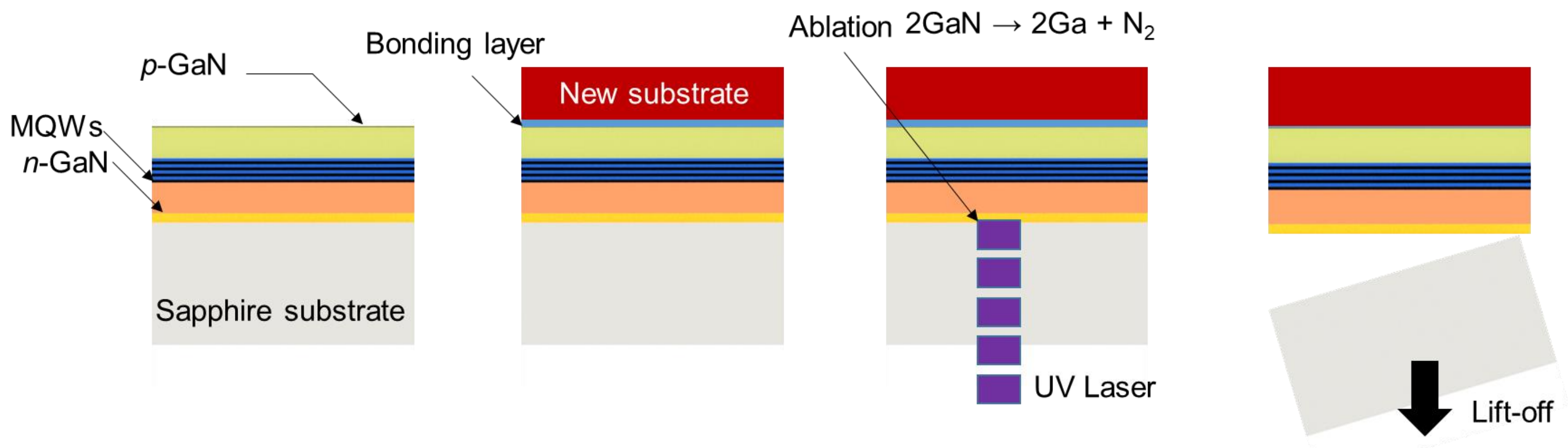
Motivation

- InGaN/GaN LEDs are epitaxially **grown on sapphire by MOVPE**, but sapphire provides poor thermal and electrical conductivity and no reflectivity.
- For sophisticated designs (e.g., high power LEDs or flexible inorganic microLEDs), tailored environment is needed [1].

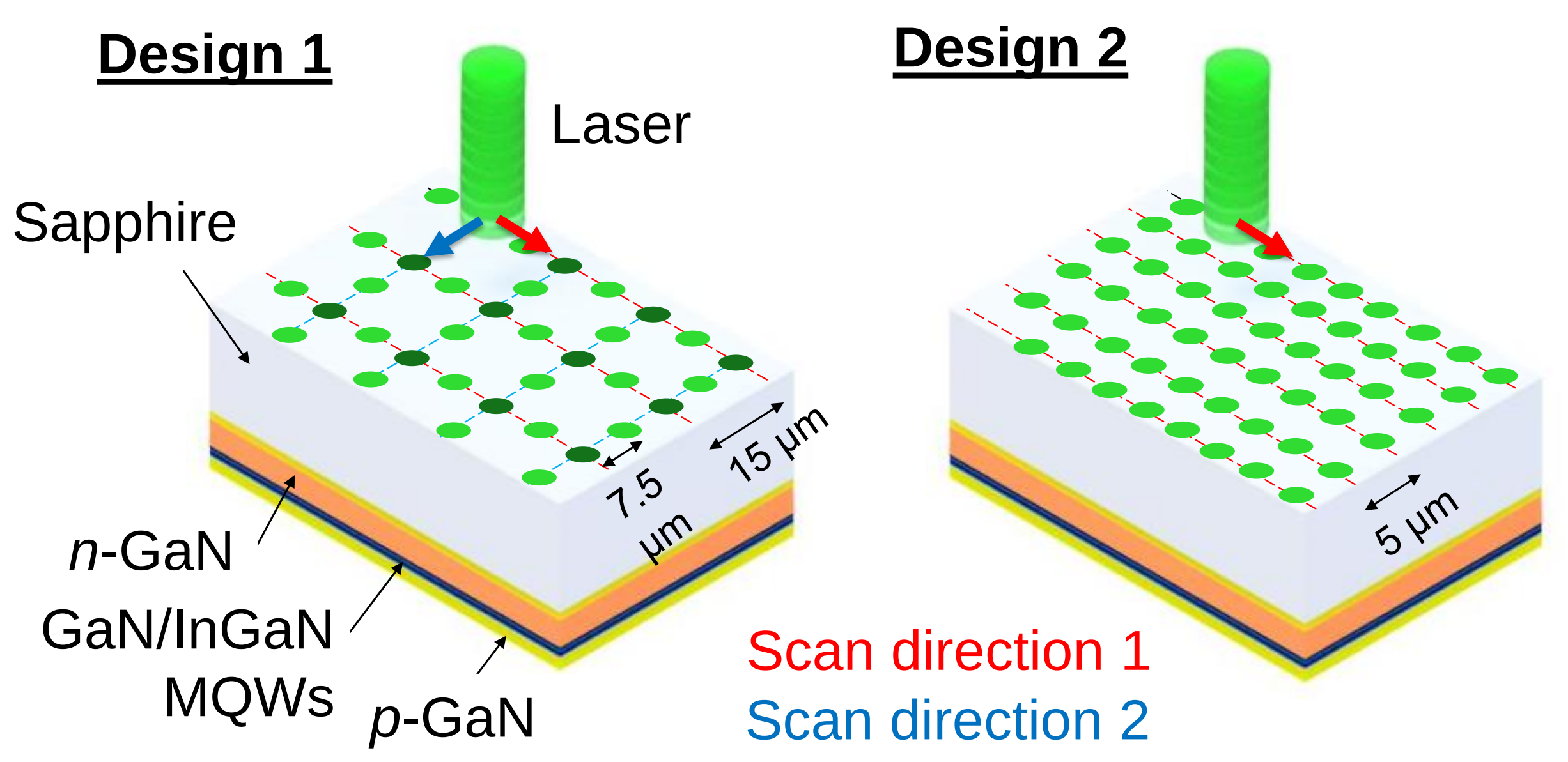
➢ Transfer of thin LED film to alternative substrates **by laser lift-off (LLO),** usually with pulsed UV lasers in the nanosecond regime [2].



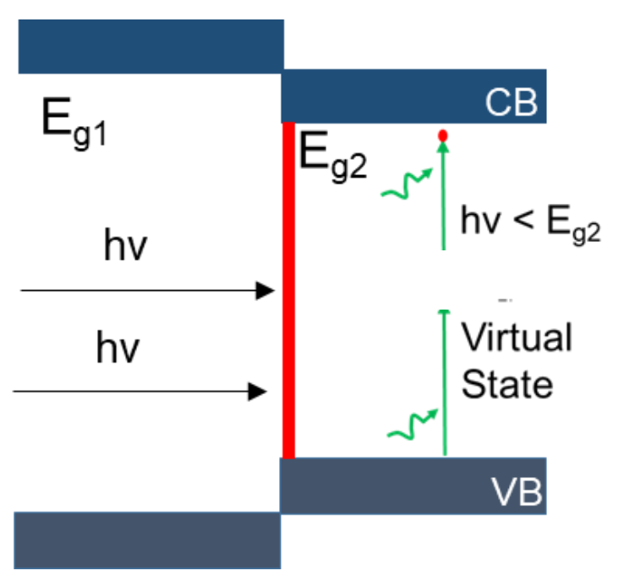
- Is LLO also feasible based on **two-photon absorption with a femtosecond laser?**

➢ benefits: reduced impact of shockwave, possible extension to AlGaN

Laser lift-off processing



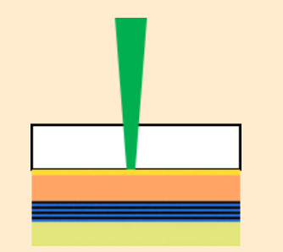
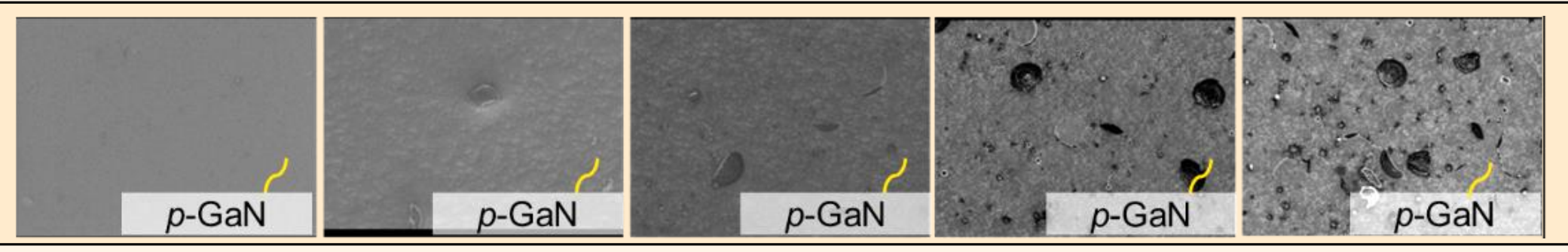
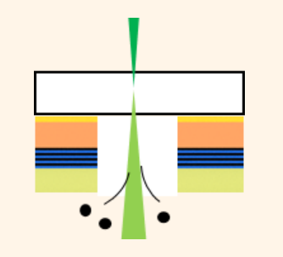
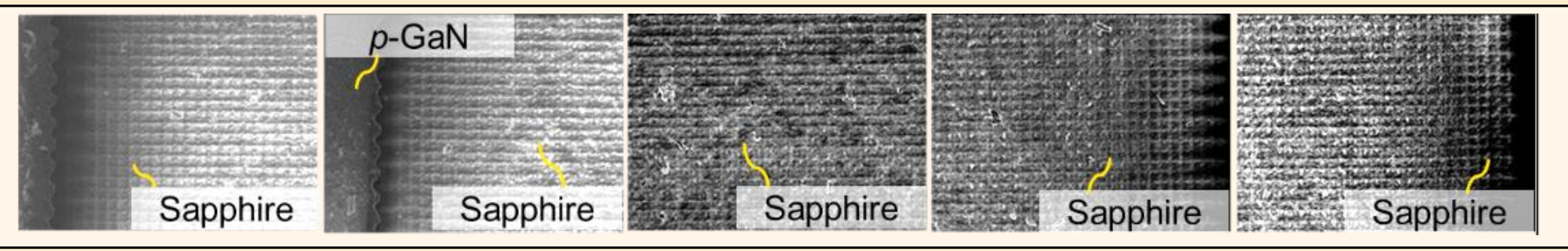
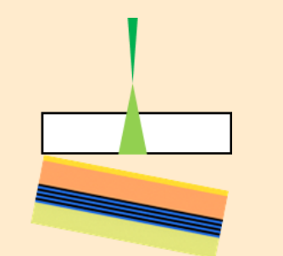
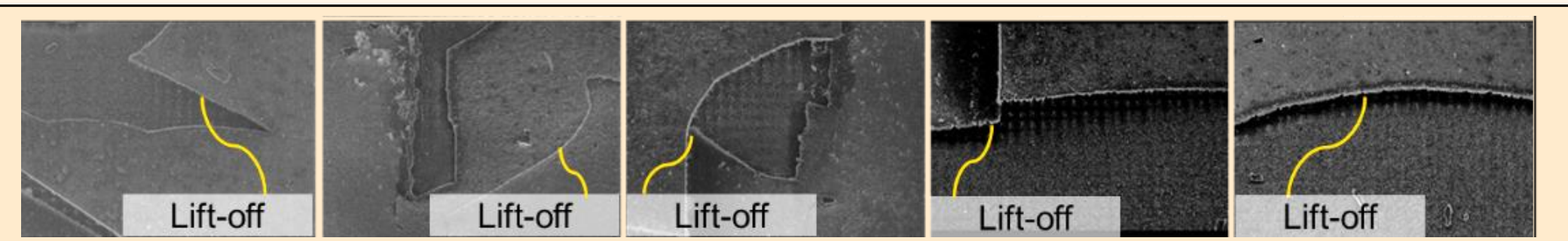
$E_{g2} < 2hv < E_{g1}$



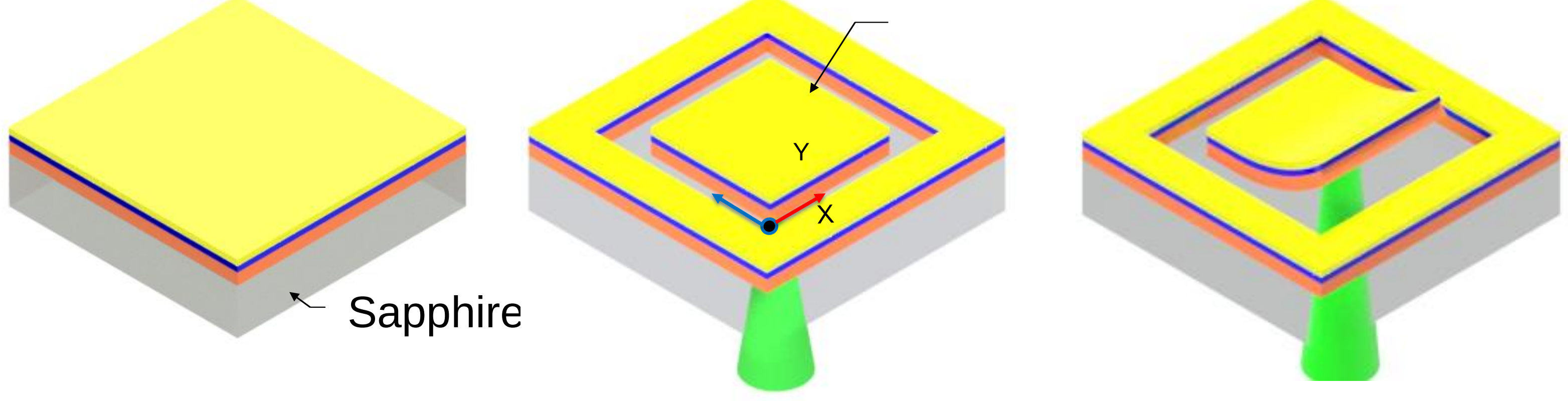
Band diagram showing two-photon absorption

GaN: E_{g2} : 3.4 eV
Sapphire: E_{g1} : 9 eV

Tests with variable pulse energy and working distance (with design 1):

	WD$_{rel}$ (mm)	Microscopic images of surface				— 100 µm
	-1					
	0					
	1					
Nominal laser power (mW)		400	450	500	550	600
Integrated fluence [J/cm²]		3.1	3.5	3.9	4.3	4.7

Processing steps for laser lift-off:



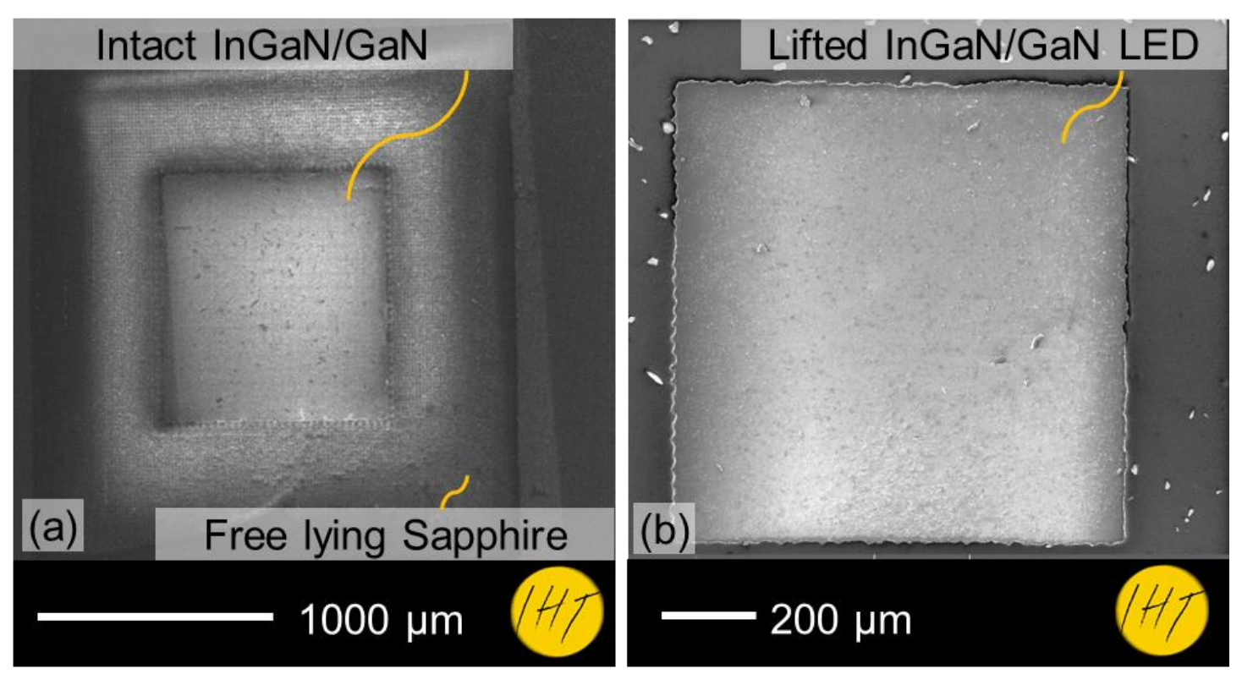
Initial wafer

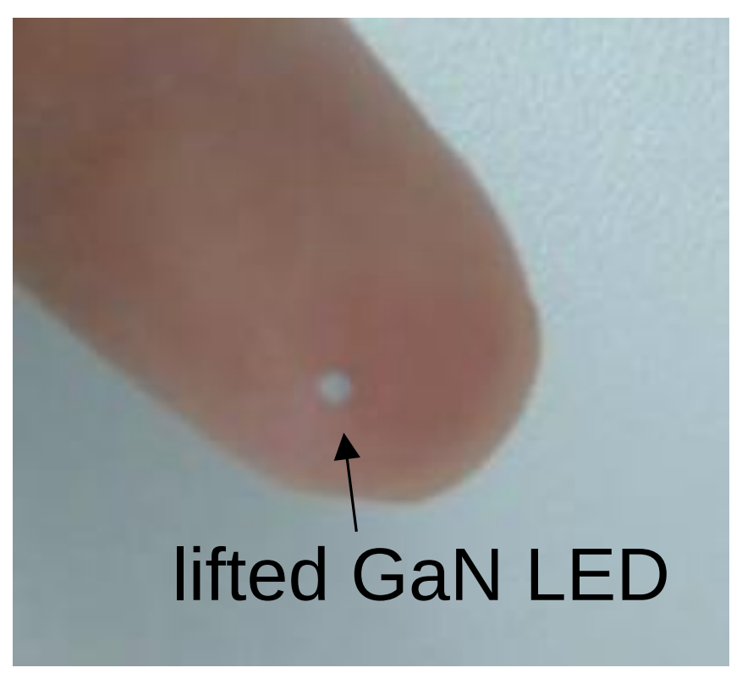
Step 1 at 1.5 W
→ 12 J/cm²

Intact
InGaN/GaN

Step 2 at 0.5 W
→ 3.9 J/cm²

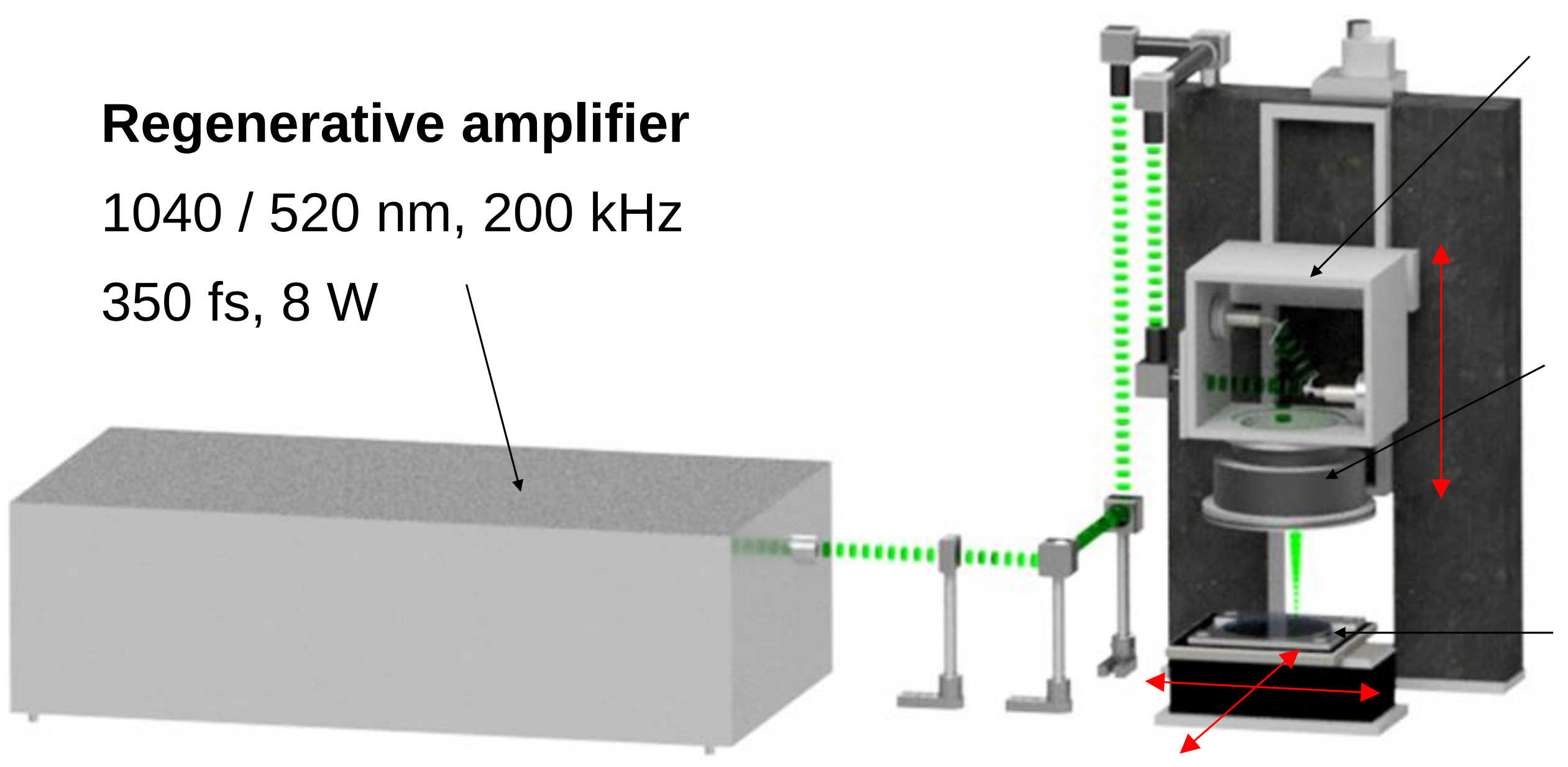
a) LED still bonded to sapphire
b) LED attached to carbon pad after lift-off





lifted GaN LED

Femtosecond laser micromachining system



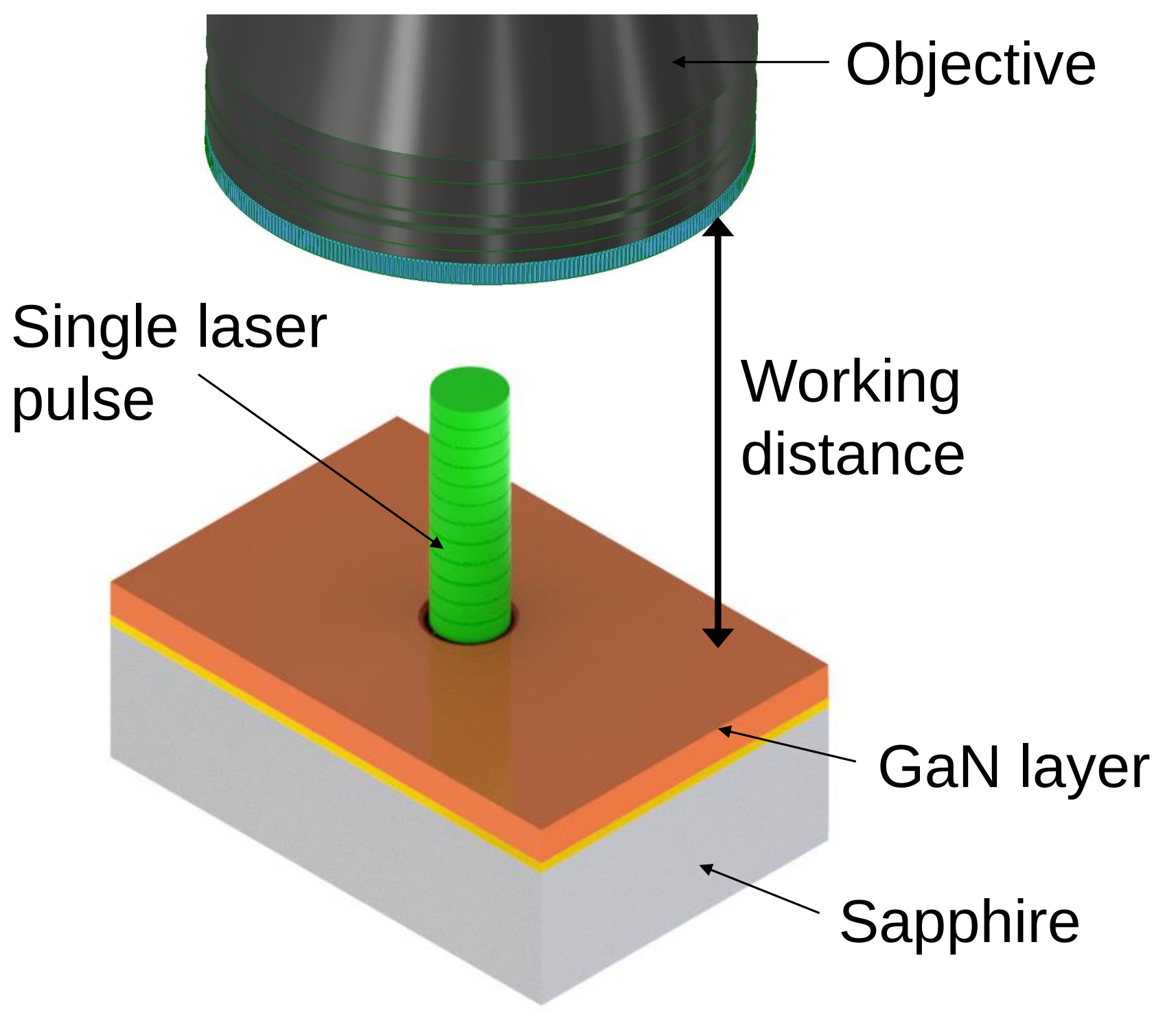
Regenerative amplifier
1040 / 520 nm, 200 kHz
350 fs, 8 W

Galvanometer scanner
Beam shifting with up to 2 m/s

Telecentric objective
f = 100 mm, *z*-stage

Sample holder
Movable *xy*-stage

Beam characterization and GaN damage threshold



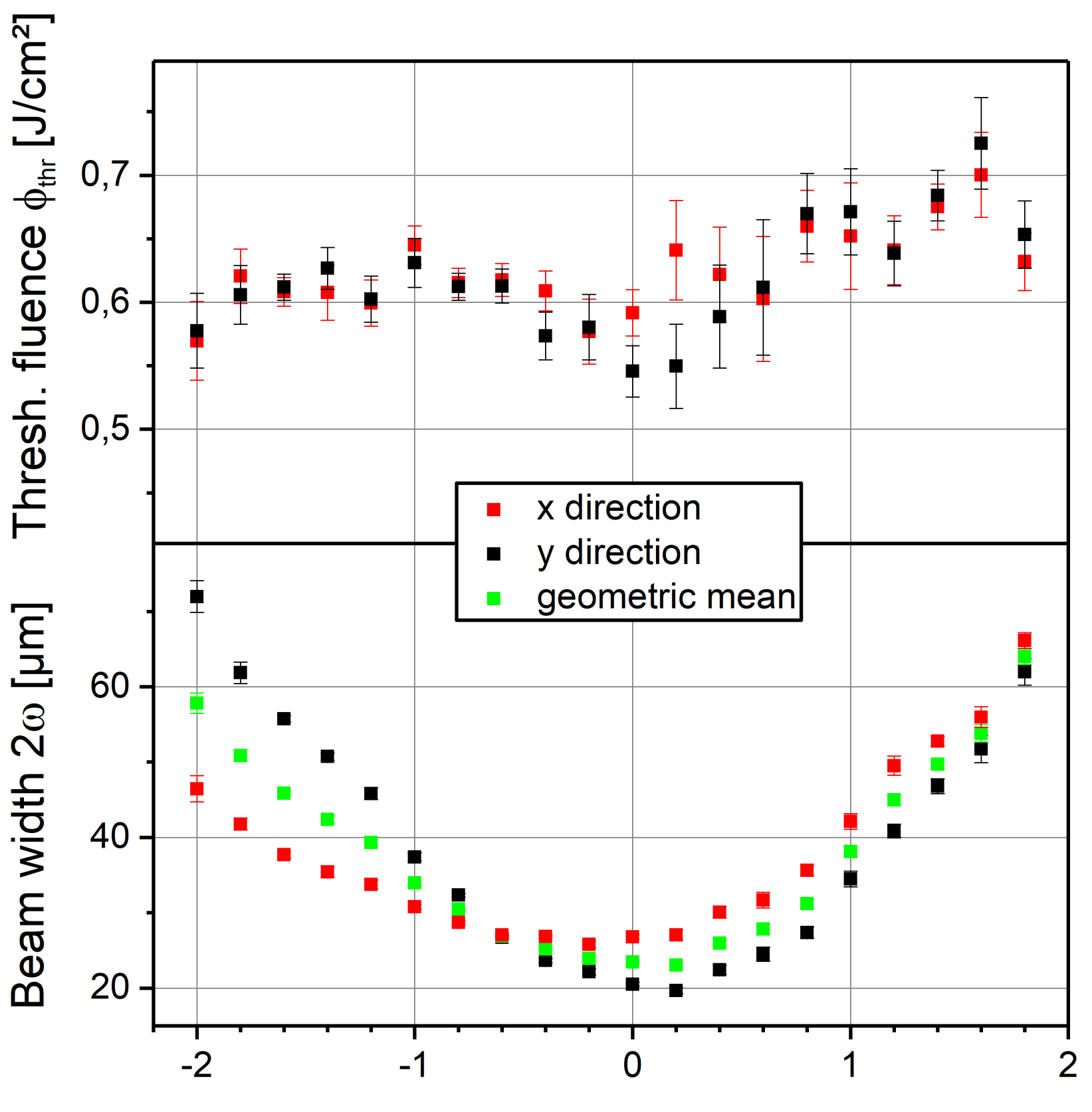
Objective

Single laser pulse

Working distance

GaN layer

Sapphire



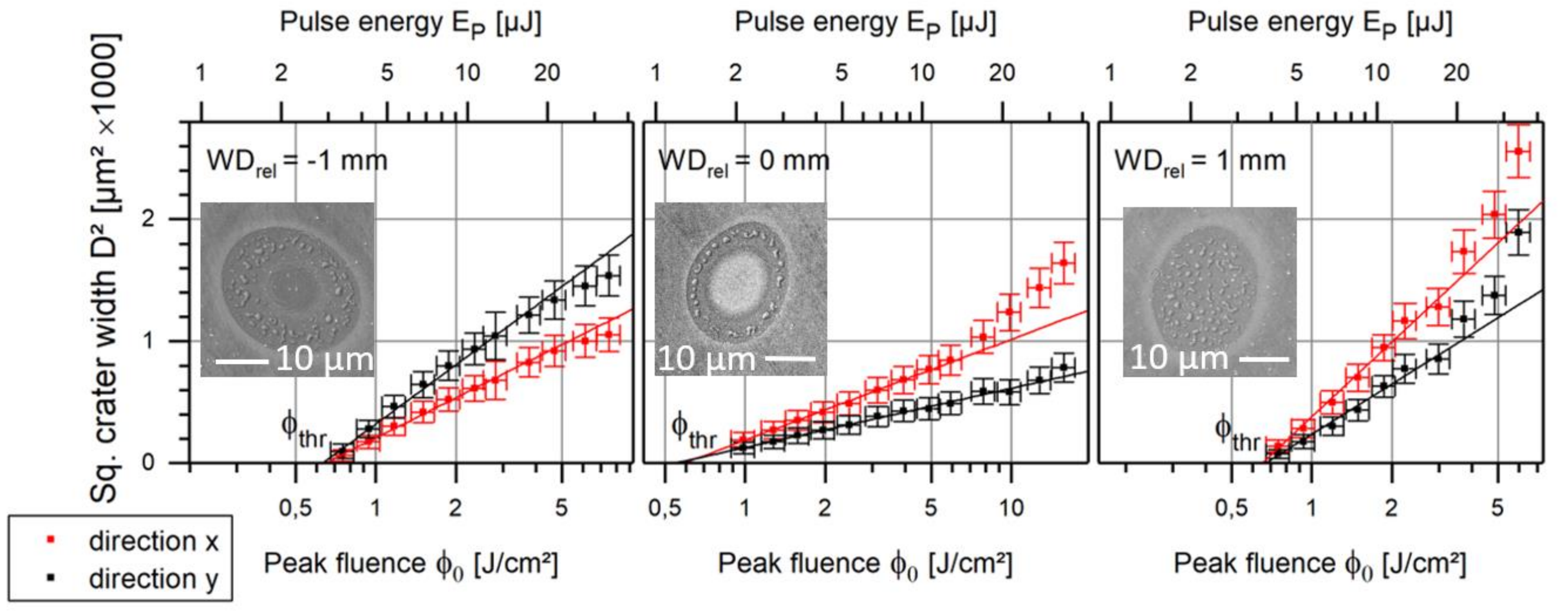
- Assuming Gaussian pulse shape [3]:

$$\phi(x, y) = \phi_0 \exp\left(-2\left(\frac{x^2}{{\omega_x}^2} + \frac{y^2}{{\omega_y}^2}\right)\right)$$

- Directing single laser pulses to GaN surface at varying pulse energy E_p
- Crater formation with diameter $D_{x/y}$, where $\phi\left(\frac{D_x}{2}, 0\right) = \phi\left(0, \frac{D_y}{2}\right) = \phi_{th}$.

Then: ${D_{x/y}}^2 = 2\,{\omega_{x/y}}^2 \log\left(\frac{\phi_0}{\phi_{th}}\right)$

- Calculated damage threshold for GaN: ~0.6 J/cm²



Acknowledgements and references

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