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Contact formation via femtosecond-laser hyperdoping in silicon optoelectronic devices

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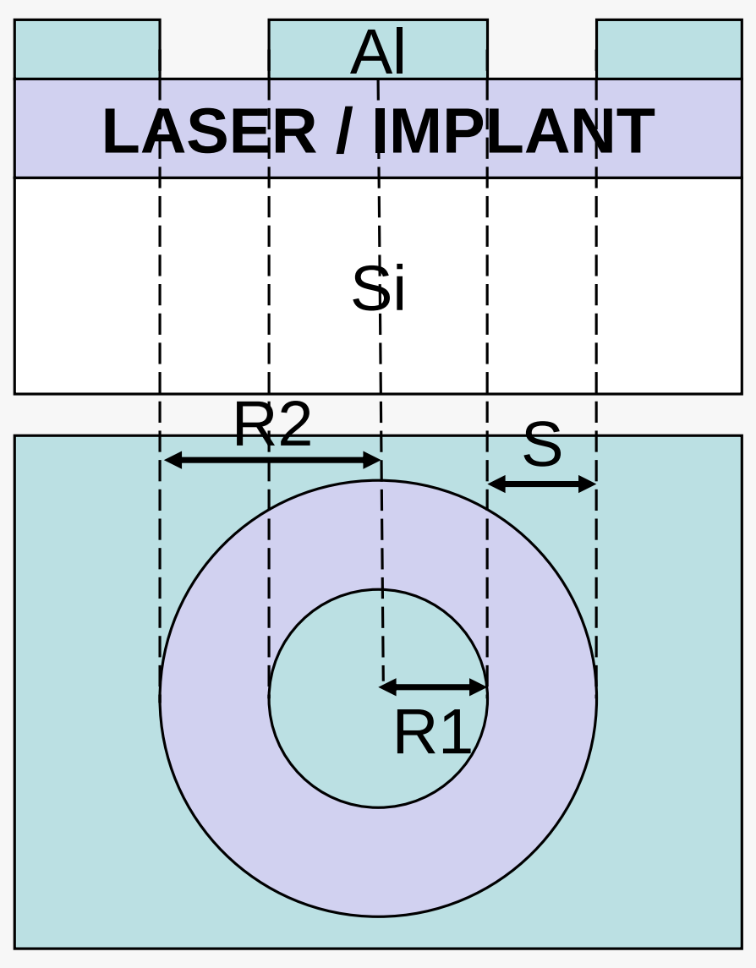
Introduction

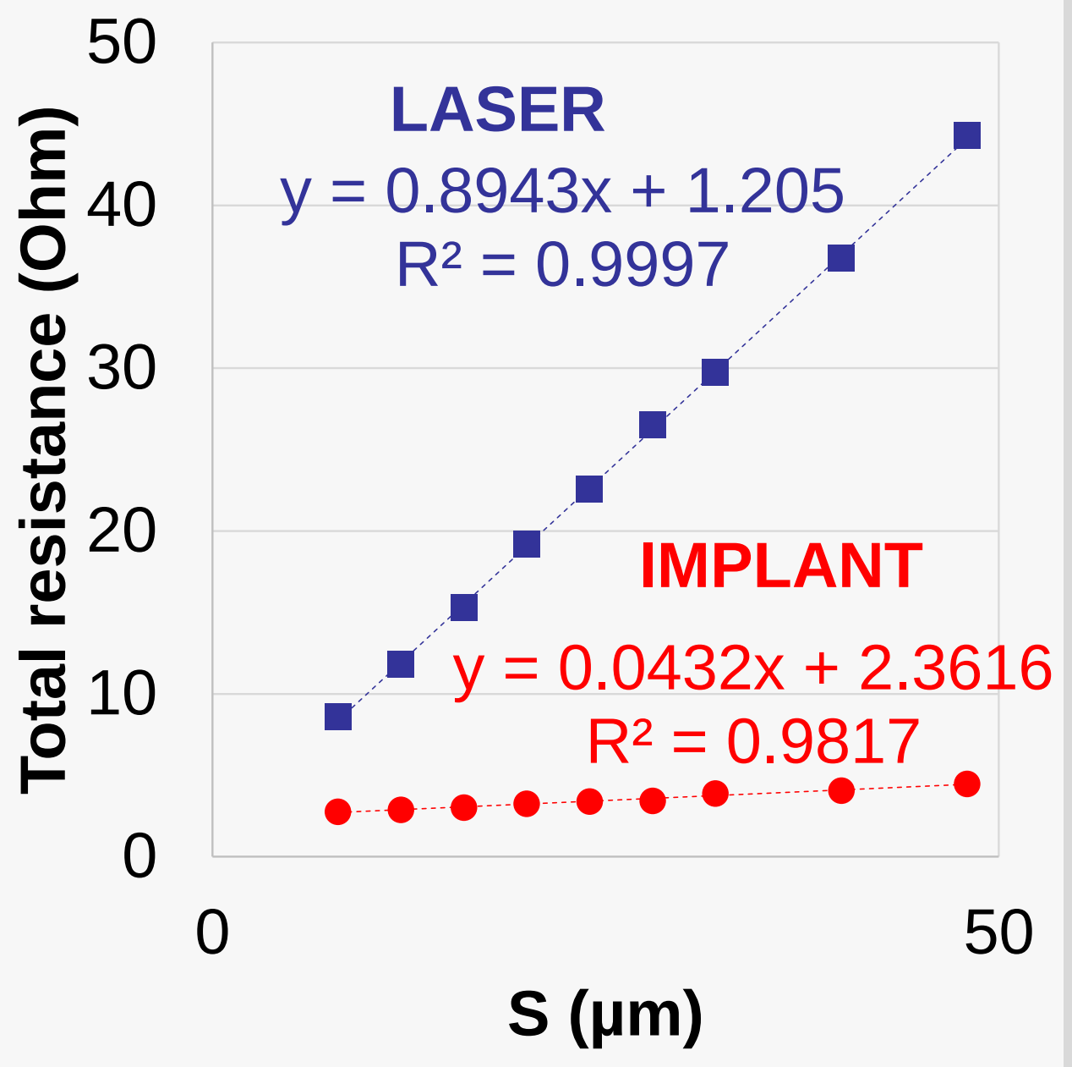
- ❖ High doping is essential for establishing Ohmic contact in optoelectronic devices. This is typically accomplished through techniques such as diffusion or ion implantation.
- ❖ Laser hyperdoping of silicon (hSi) has advantages over traditional methods, such as lithography-free, low cost, short processing time and extended absorption spectrum.
- ❖ We compare the ohmic contact quality between laser hyperdoping and traditional ion implantation doping by transmission line measurement.
- ❖ We further use a black silicon (bSi) photodiode (PD) as a proof-of-concept device to investigate the feasibility of replacing implanted ohmic contacts on backside with the fs-laser hyperdoping by assessing the device performance.

CTLM measurement

- ❖ We used Circular Transfer Length Measurement (CTLM) instead of normal TLM with the advantage of no active area isolation. High-resistivity (>10 kΩ·cm) p-type Si was doped either by sulfur-hyperdoping or by phosphorus ion implantation as a reference, covered with sputtered Al for contact metal and sintered at 425 °C.



- ❖ The typical doping concentration with both techniques is as high as >1E20 cm^{-3}, but laser doping results in much higher sheet resistance (R_{sh}) due to non-equilibrium dopant states while implantation results in mostly electrically active dopants.



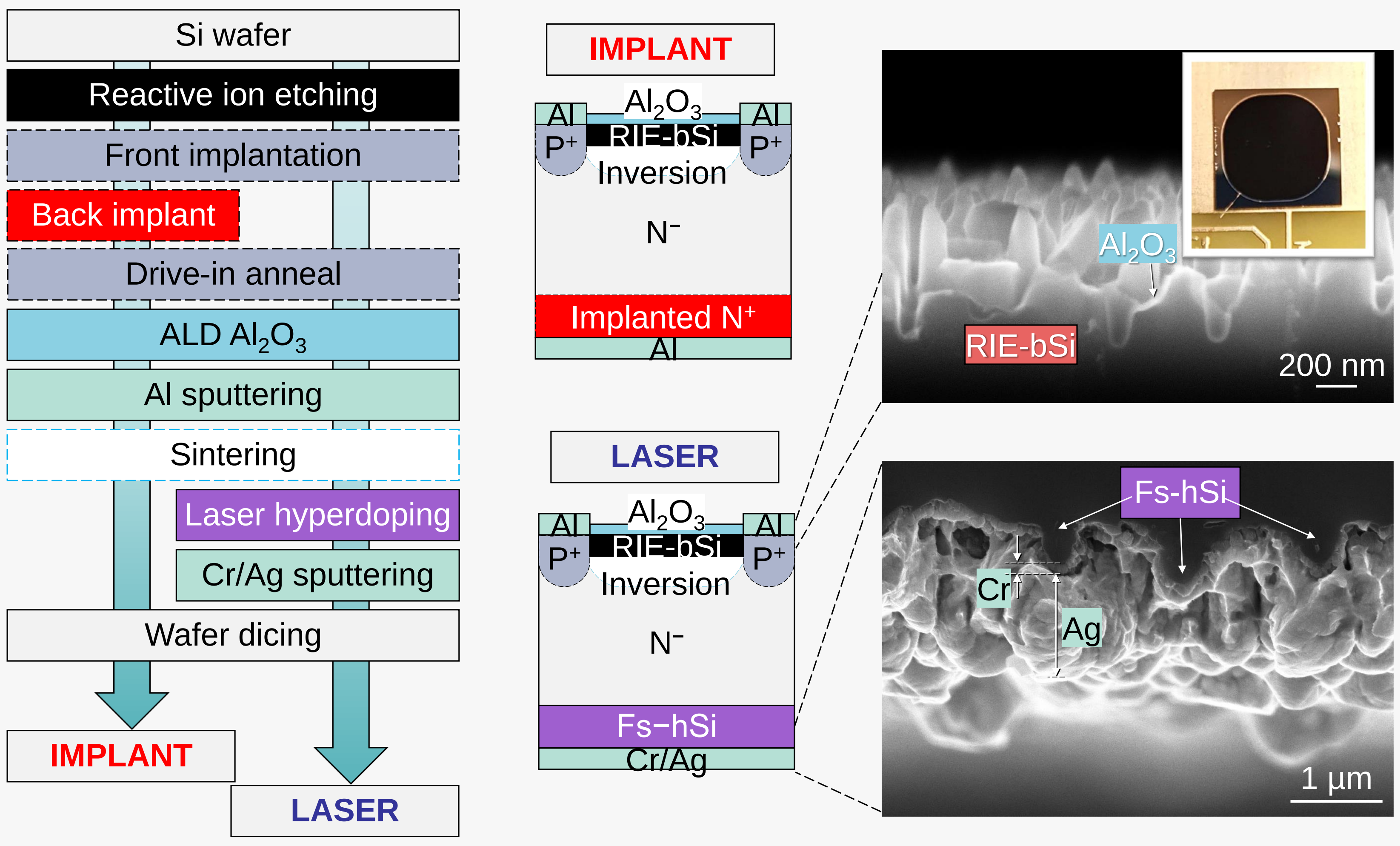
	R_{sh} (Ω/□)	ρ_C (Ω cm²)
IMPLANT	54	4.1E-04
LASER	1124	5.1E-06

- ❖ The (specific) contact resistance (ρ_C) is much lower with LASER contact indicating excellent ohmic contact quality with sintered Al metal. There are also other metals such as Cr/Ag that can form high-quality ohmic contact even without sintering.

Device Fabrication

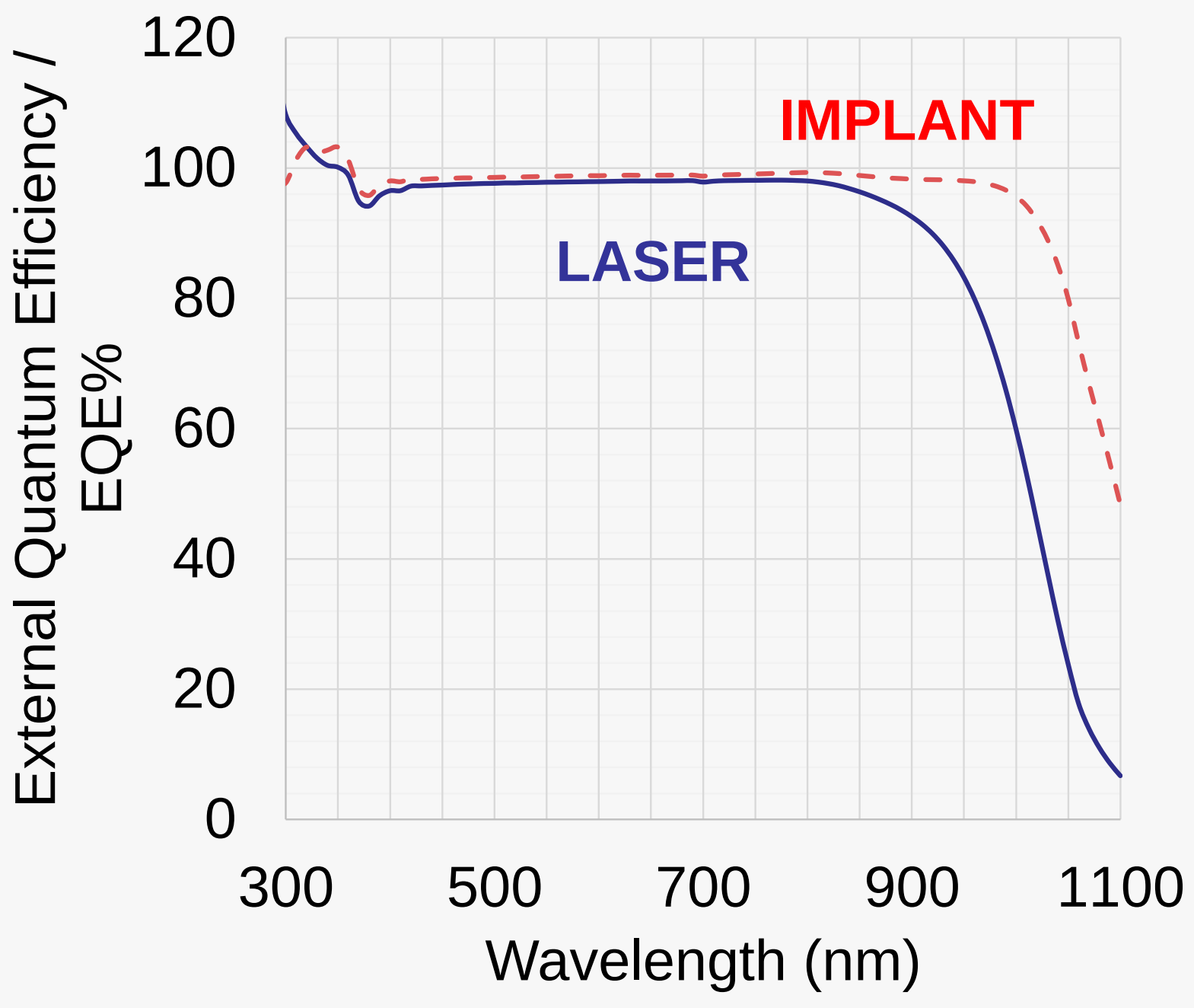
We compare black silicon photodiodes featuring nanostructures on the front surface for optimal light absorption, using two distinct back contact schemes:

- ❖ Fs-laser hyperdoped back contact (**LASER**)
- ❖ Implanted back contact (**IMPLANT**).



Device characterization

- ❖ Both LASER and IMPLANT PDs exhibit nearly perfect EQE from UV to Vis wavelengths (300 – 750 nm). However, the EQE of the LASER PD drops rapidly from around 800 nm due to laser damage and enhanced recombination for carriers generated at or close to the rear surface. This is also confirmed with blackbody responsivity, where IMPLANT PD has higher signal.



- ❖ The dark current in LASER PD is slightly reduced compared to IMPLANT PD, confirmed by noise measurements in photovoltaic mode.

Conclusion

- ❖ The contact formed from laser hyperdoping shows low contact resistance and high sheet resistance compared to implanted contact.
- ❖ The LASER contact can be utilized in a range of optoelectronic devices where an ohmic contact is required.
- ❖ However, the laser-induced damaged layer compromises some aspects of optoelectronic performance in localized areas.
- ❖ Achieving superior device performance beyond 1100 nm necessitates a comprehensive understanding of the hyperdoped material, a carefully designed device structure, and optimized fabrication technology.

Related publications

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