Two color laser ablation: enhanced yield, improved quality

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Abstract

We report on recent results of laser ablation in semiconductors obtained by simultaneous irradiation of the sample with a superposition of the fundamental beam (λ=1064 nm) and a small amount of its second or third harmonic (SH,TH). Keeping the total energy fluence constant, the harmonic radiation serves to excite electrons into the conduction band to get the ablation process started. In this fashion, the ablation yield could be increased significantly. In addition, the ablation quality was improved in terms of surface smoothness. This technique works well for nano- and picosecond pulses where robust and inexpensive sources are available; for femtosecond pulse durations, the carrier excitation by multiphoton processes turns out to be more efficient than harmonics seeding.

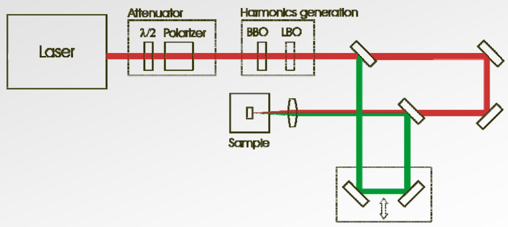
Laser Systems

Nd:VAN DPSS Laser
(HighQLaser)
Pulse duration: 10 ps
Wavelength: 1064 nm

Nd:YAG Laser
(Quantel)
Pulse duration: 5 ns
Wavelength: 1064 nm

Ti:Sapphire Laser
Pulse duration: 50 fs
Wavelength: 800 nm

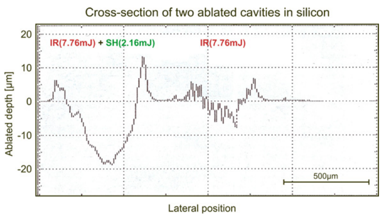
Setup



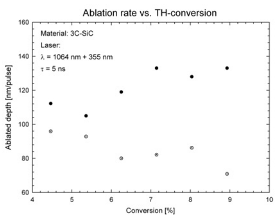
Schematic setup for the harmonics seeding experiments. The time delay is used to study the ablation behaviour as a function of the delay between the fundamental and the harmonics pulse.

Harmonics seeding: Nanosecond pulses

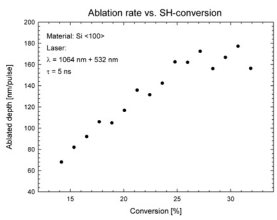
Nanosecond pulses:
Overall yield enhancement of 240 %
Improved surface quality



Depth profile of ablation cavity produced by IR + harmonics seeding (left) and IR only (right), respectively. Two-color ablation yields smoother surfaces and highly enhanced efficiency.



Ablation of SiC with third harmonics seeding. Conversion is limited to 9 %

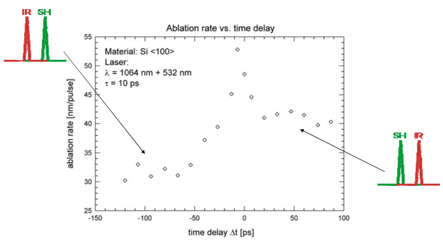


The ablated depth increases approx. linearly with increasing SH-conversion up to about 27%. For higher SH values the ablation enhancement saturates.

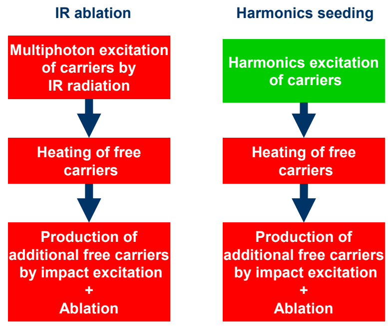
Harmonics seeding: Picosecond pulses

Picosecond pulses:
Overall yield enhancement of 70 %
Improved surface quality

Femtosecond pulses:
The effect becomes insignificant, since sufficient conduction band population is provided by multiphoton absorption.



Ablation mechanism



Theory

Two-photon excitation rate

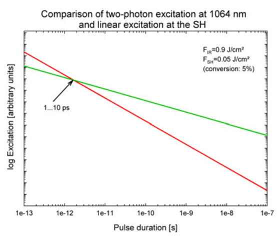
$$\left.\frac{\partial n_e}{\partial t}\right|_{TPA} = \frac{\beta_\omega I_\omega^2}{2\hbar\omega}$$

α…linear absorption coefficient
b…Two-photon absorption coefficient
I…Intensity transmitted into the sample

Linear excitation @ 532 nm

$$\left.\frac{\partial n_e}{\partial t}\right|_{lin} = \frac{\alpha_{2\omega} I_{2\omega}}{2\hbar\omega}$$

Absorption coefficients (@300K)
for intrinsic silicon:
λ = 1064 nm: $\alpha = 0{,}001 \cdot 10^6\ m^{-1}$ → negligible
$\beta = 1$ cm/GW
λ = 532 nm: $\alpha = 1 \cdot 10^6\ m^{-1}$



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