Quality and yield enhancement of IR-laser ablation by harmonics seeding

S. Zoppel[1,2] and G.A. Reider[1]

[1]Vienna University of Technology, Photonics Institute
Gusshausstr. 27-29/387, 1040 Vienna, Austria
[2]Vorarlberg University of Applied Sciences, Research Centre for Microtechnology
Hochschulstr. 1, 6850 Dornbirn, Austria

Abstract

Laser ablation of semiconductors with nano- and picosecond IR sources exhibiting a quantum energy below the band gap is characterized by low ablation rates accompanied by a poor surface quality due to weak absorption. This can be overcome by the use of frequency converted lasers, at the expense, however, of a considerable energy loss by the conversion process.

We present a method which combines high energy efficiency and good surface quality by simultaneous irradiation of the sample with a superposition of the fundamental beam (λ=1064 nm) and a small amount of its second (SH) or third harmonic (TH), generated in a thin nonlinear crystal. Conserving the total energy fluence, the high absorption at the harmonic wavelength leads to an electron population in the conduction band which is sufficient to start the ablation process by absorption of the IR radiation. In this fashion, the ablation yield can be increased significantly. In addition, the ablation quality was demonstrated to improve in terms of surface smoothness. While the effect is insignificant for femtosecond laser pulses, it becomes quite efficient for longer pulse durations, where inexpensive and robust laser sources are easily available.

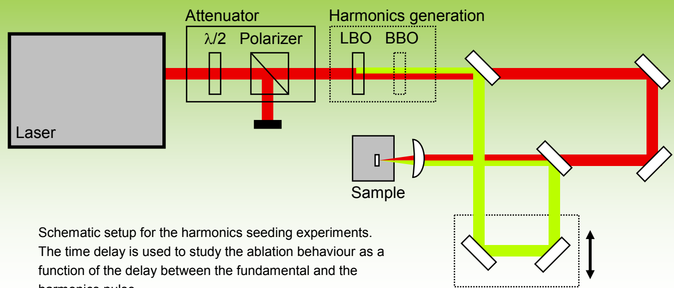
Laser Systems

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

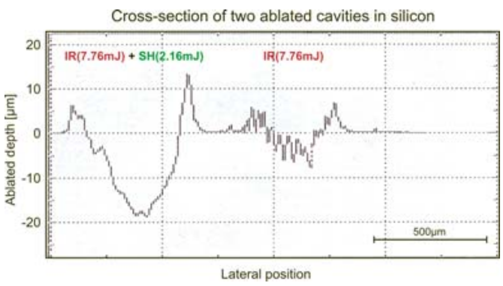
Setup



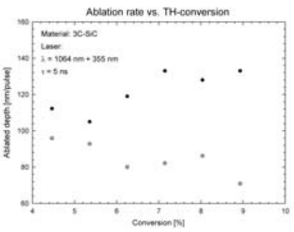
Schematic setup for the harmonics seeding experiments. The time delay is used to study the ablation behaviour as a function of the delay between the fundamental and the harmonics pulse.

Harmonics seeding: Nanosecond pulses

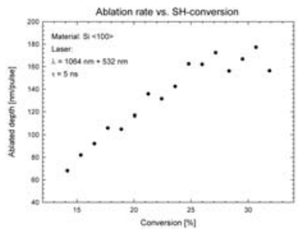
Nanosecond pulses:
Overall yield enhancement of 240 %
Improved surface quality



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 %

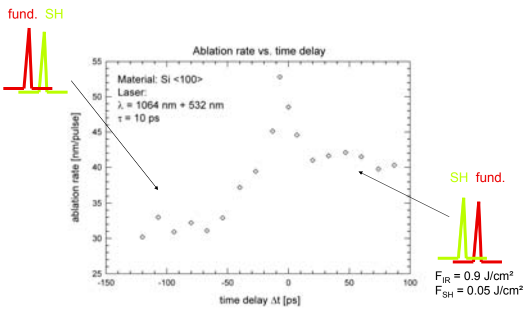


The ablated depth increases approx. linearly with increasing SH-conversion up to about 27%. For higher SH values the ablation enhancement saturates.

Harmonics seeding: Ultrashort pulses

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

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



Ablation mechanism

IR ablation	Harmonics seeding
Multiphoton excitation of carriers by IR radiation	Harmonics excitation of carriers
↓	↓
Heating of free carriers	Heating of free carriers
↓	↓
Production of additional free carriers by impact excitation + Ablation	Production of additional free carriers by impact excitation + Ablation

Two-photon excitation rate

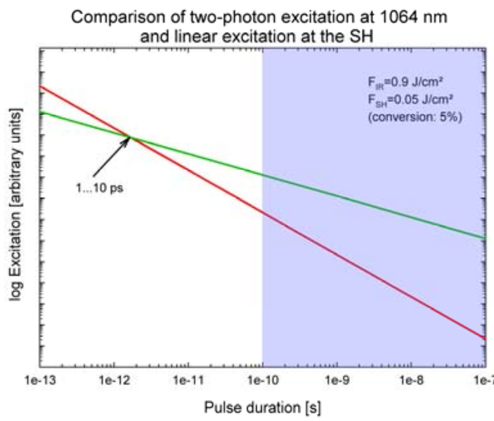
$$\left.\frac{\partial n_e}{\partial t}\right|_{TPA} = \frac{\beta_\omega I_\omega^2}{2\hbar\omega}$$

α…linear absorption coefficient
β…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 of Si (@300K)
λ = 1064 nm: $\alpha = 0{,}001\cdot 10^6\ m^{-1}$ → negligible
β = 1 cm/GW
λ = 532 nm: $\alpha = 1\cdot 10^6\ m^{-1}$



Conclusion: Significant improvement by SH-seeding for ps- and ns- pulses

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