

Compact Ultrafast Lasers

Thin Film Structuring for Photovoltaic Applications



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Abstract

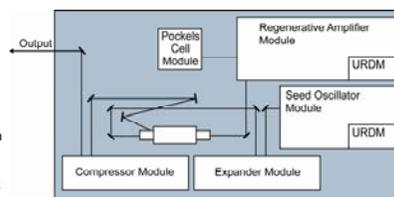
Over the past 15 years, diode-pumping of solid-state lasers as well as new mode-locking techniques have contributed to the development and enhancement of commercial ultrafast laser systems. The current development status encourages a growing number of users in industry, bio medicine, metrology and other areas to utilize the advantages of ultrafast laser systems for their applications. Aside from permanent efforts to adjust laser system specifications to user-defined process requirements, an important goal is to develop more compact and stable systems for easy integration into production lines.

As a representative application example, we demonstrate the potential of ultrafast lasers for structuring TCO and metallic layers for thin film solar cells. High repetition rates and nonthermal ablation enables high quality structuring combined with process rates meeting industrial demands.

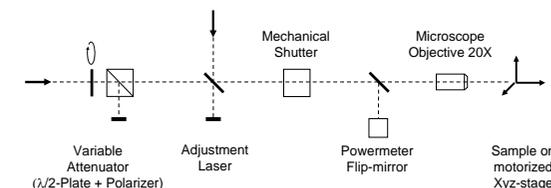
Laser System: femtoREGEN

Chirped Pulse Regenerative Amplifier with Seed Laser

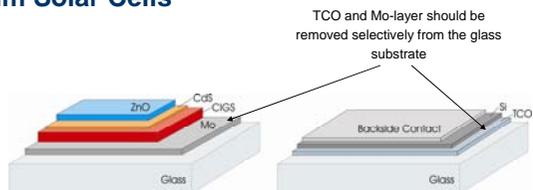
Yb:Glass
Wavelength $\lambda = 1040$ nm
Pulse duration $\tau = 300$ fs
Pulse energy $E_p = 130$ μ J
Rep-rate $f_p =$ up to 10 kHz



Optical Setup



Thin Film Solar Cells

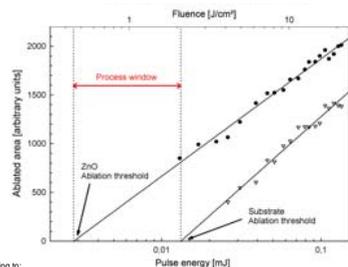


TCO and Mo-layer should be removed selectively from the glass substrate

Determination of the Process Window

Beam diameter and threshold fluence

Both parameters were derived from the dependence of the square of the ablated area versus pulse energy



Method according to: J.M.L.S., Opt. Lett. 7(5), 196-9(1982)

$$\phi(r, z) = \phi_0 e^{-2r^2/w^2}$$

$$\phi_{th} = \phi_0 e^{-2A_0/A_L}$$

$$A_0 = \frac{A_L}{2} \ln\left(\frac{\phi_0}{\phi_{th}}\right)$$

The ablation spot area is a linear function of the logarithm of the pulse energy (ϕ_0 prop. E_p)

Beam diameter: Determined by the gradient

Ablation threshold: Intersection with the energy-axis

- High accuracy (measuring on the sample surface)
- For tightly focused laser beams

Results

Multipulse Threshold Fluences:

Glass substrate: 2.6 J/cm²
Molybdenum Mo: 0.7 J/cm²
Zinc oxide ZnO: 0.44 J/cm²
Tindioxide SnO₂: 0.73 J/cm²

Focusing the beam to diameters of a few microns

Pulse energy in the sub- μ J range is sufficient to achieve ablation → laser systems providing high repetition rates could be used

→ cavity dumped laser sources

Minimal Waste of Active Area

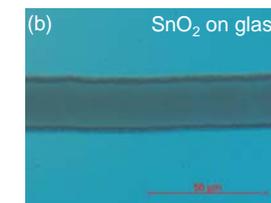
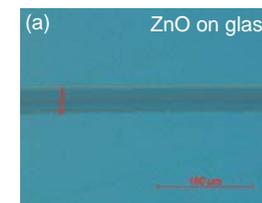
High Process Speed

Complete removal of Molybdenum

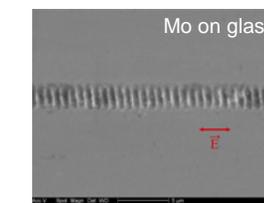
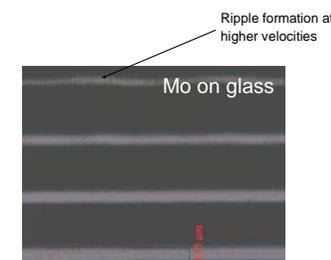
800 nJ, 1 mm/s @ 10 kHz

→ Extrapolating the ablation parameters to a repetition rate of 1 MHz (cavity dumped systems)

100 mm/s Process Speed



Thin layer of zinc oxide (a) and tin dioxide (b) selectively ablated from the glass substrate with a fluence of 0.5 J/cm² and 0.8 J/cm², respectively (10 kHz, 1 mm/s). The phase contrast images do not give any evidence for a refractive index change of the substrate caused by thermal load. (focusing lens: f = 50)



Thin film of molybdenum on glass structured at different velocities (0.5, 1, 2 and 4 mm/s) with a pulse energy of 800 nJ. The beam was focused to a diameter of 8.6 μ m

Line ablated in Molybdenum with linear polarized light. At fluences close to the ablation threshold the well known effect of ripple formation could be observed. By employing circular polarization this effect could be practically avoided