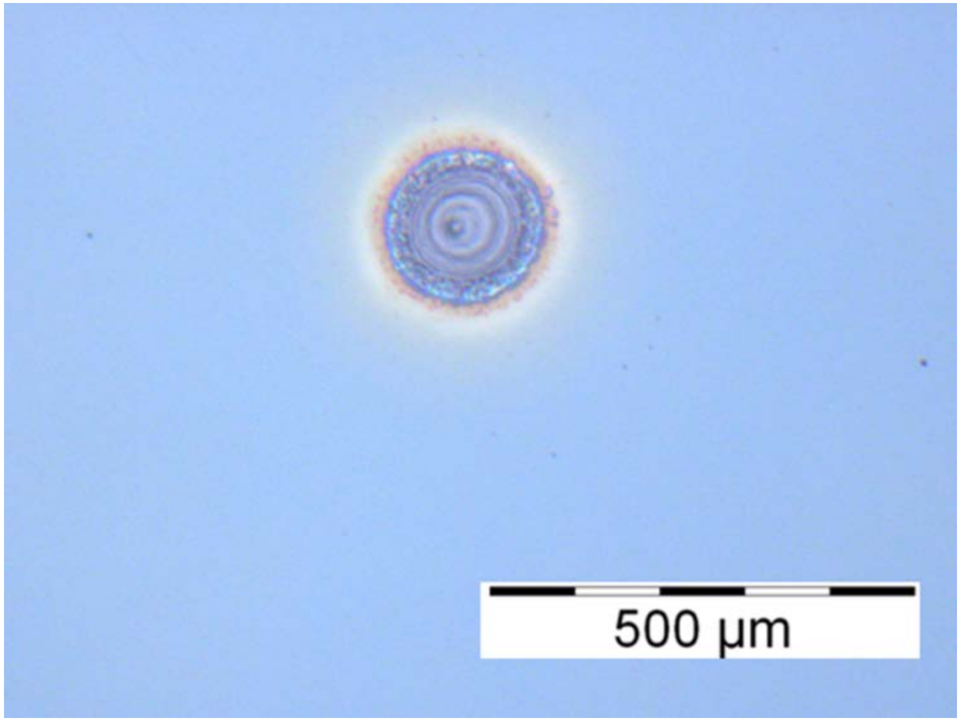
DIELECTRIC COATINGS – LASER DAMAGE LIMITATIONS

LA³Net – Symposium

Nov 5th 2013



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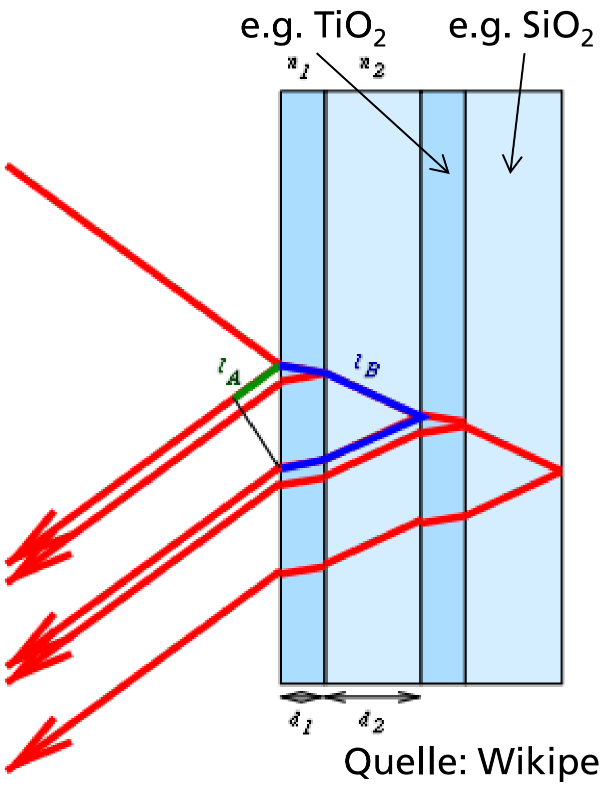
ILT

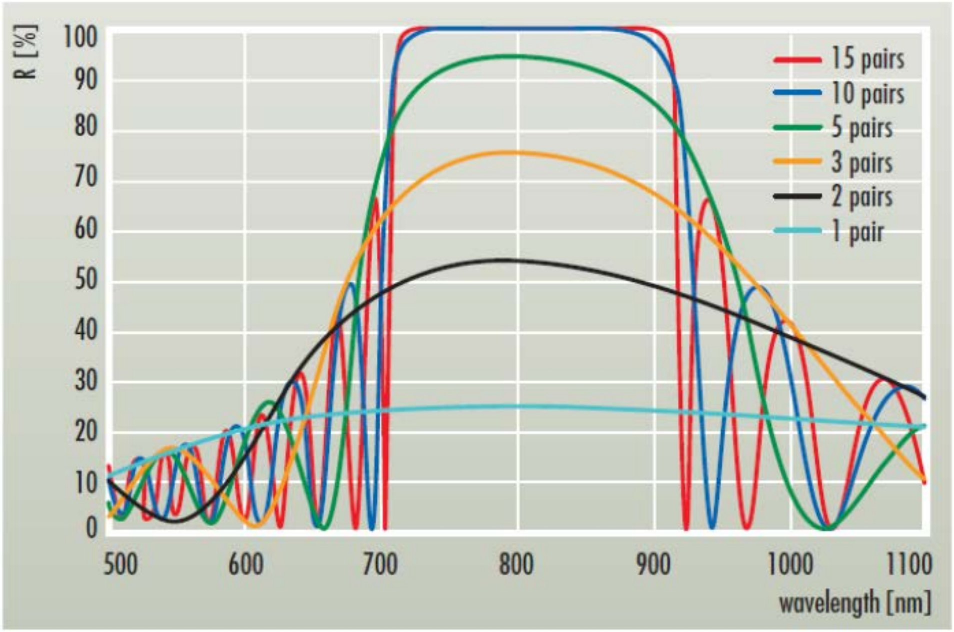
AGENDA

- Dielectric Coatings - Basics
- Laser-Induced Damage Mechanisms and Damage Morphologies
- Scaling Laws and Influencing Factors
- LIDT-Testing
- Take-Home Messages

Dielectric Coatings: Working Principle



Quelle: Wikipedia



Quelle: Layertec

HR: $l_B - l_A$ = lambda
AR: $l_B - l_A$ = lambda/2

Coating Processes – Physical Vapour Deposition

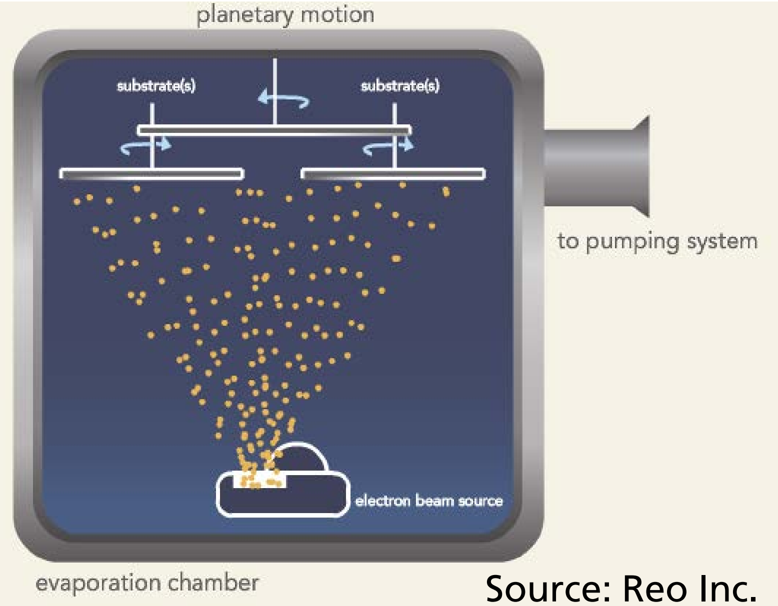
■ e^--Beam Evaporation	Thermal Evaporation
■ Ion Assisted Deposition (IAD)	
■ Magnetron Sputtering	Sputtering
■ Ion Beam Sputtering (IBS)	

Link: Coating Processes Videos (Reo Inc., Boulder, CO, USA)
http://www.reoinc.com/technical-resources/cat/78/technical_tutorials/article/Coating_Process_Tutorial/

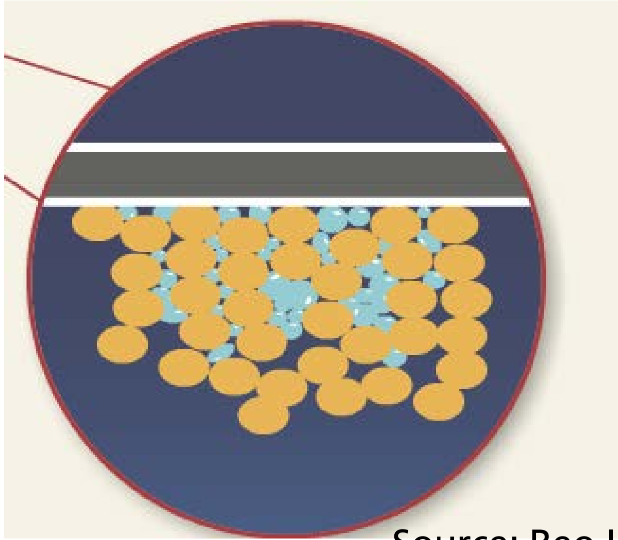
E-Beam

- Low kin. energy of ad-atoms
- Substrates heated

- 🙂 „Simple and cheap“
- 🙂 Coating mat. from deep UV to far IR
- 🙂 Well established
- ☹ Porous, column-like structure
- ☹ Water accumulation in pores
  => spectral shift with T and p
- ☹ Low mechanical durability
- ☹ Increased scatter losses
- ☹ Increased production tolerance



Source: Reo Inc.

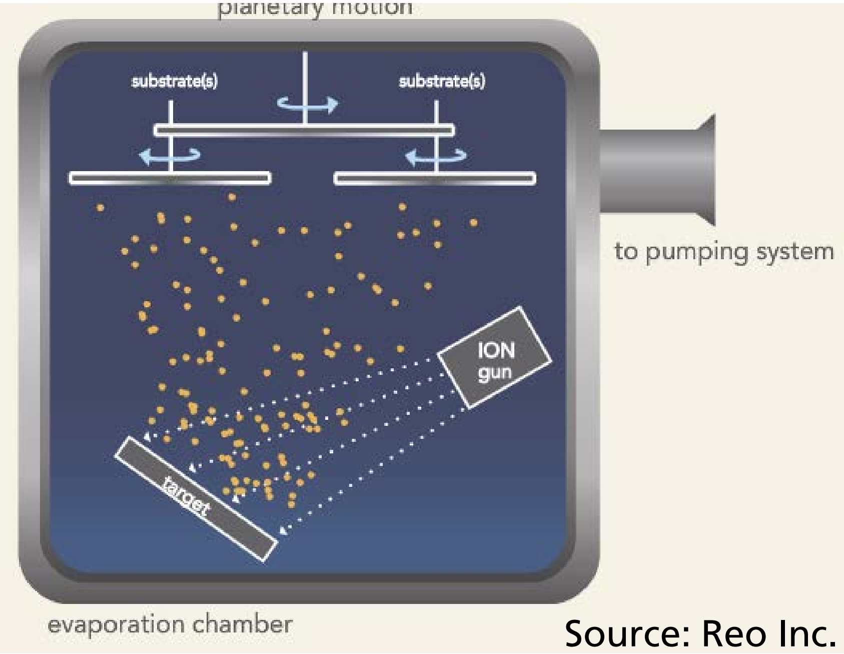


Source: Reo Inc.

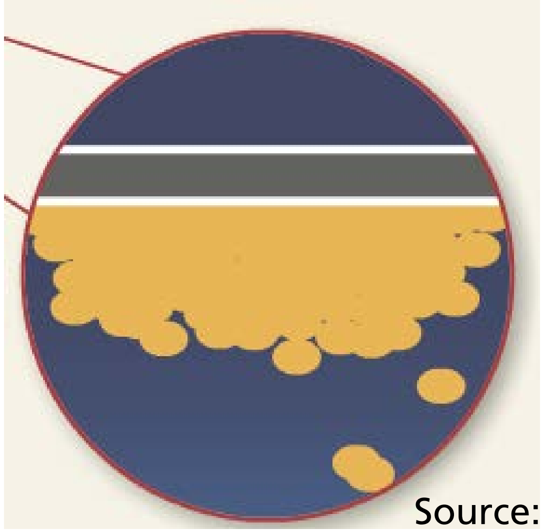
IBS

- High kin. energy of ad-atoms
- Many parameters for controlling the process

- ☺ Very dense layers close to bulk mat.
- ☺ Low absorption and scattering losses
- ☺ No spectral shifts
- ☺ Very stable and durable
- ☺ Well established
- ☹ „Complex and expensive“
- ☹ Not applicable in deep UV and far IR
- ☹ Can impose stress on substrate



Source: Reo Inc.



Source: Reo Inc.

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Definitions

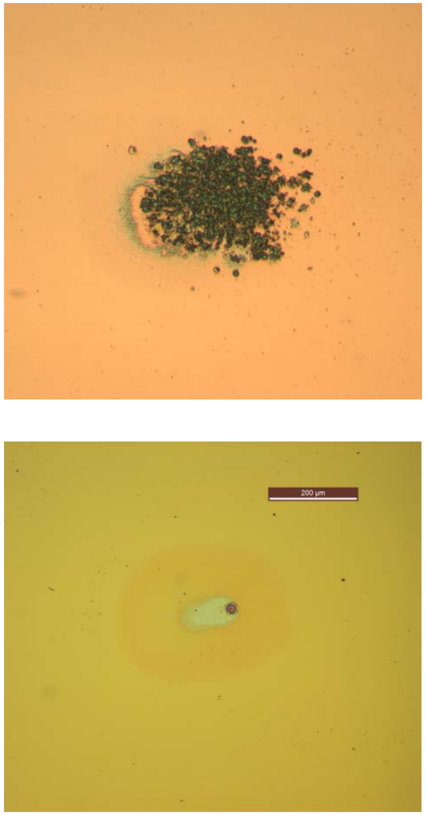
- Laser-Induced Damage:
  Any "detectable" permanent change of optical properties and/or mechanical structure of the coating caused by laser radiation
- Laser-Induced Damage Threshold (LIDT):
  Highest energy (or power) density that does not cause damage

Damage Mechanisms

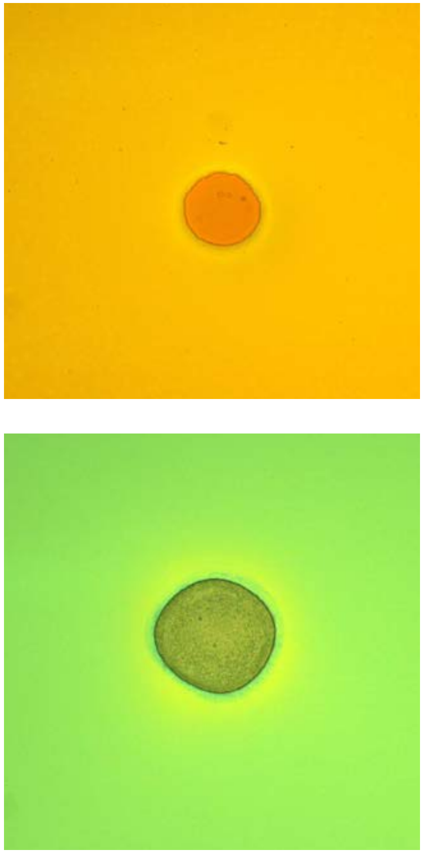
- Thermal Damage (~ 100 ns to cw):
  deposited heat triggers thermal fracture or local melting
- Dielectric Breakdown (~10 ps to 100 ns):
  electric field of the laser beam is large enough to pull electrons out of the molecular compound
  shock wave destroys coating
- Multiphoton Absorption (< 10 ps):
  Free electrons generated by multi-photon absorption (in strong field area of the beam). No transfer of energy to the lattice during pulse. Actual damage occurs after the pulse has passed, when energy is transferred to the lattice
- Often triggered by defects, scratches, voids, particles, colour centers, …

Damage Morphologies

defect-driven

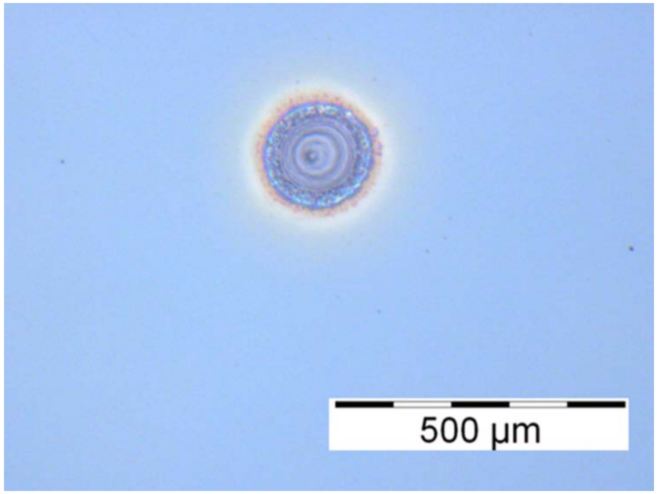


not defect-driven



Damage Morphologies

thermal



dielectric

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Before we start with it…

- Scaling laws are

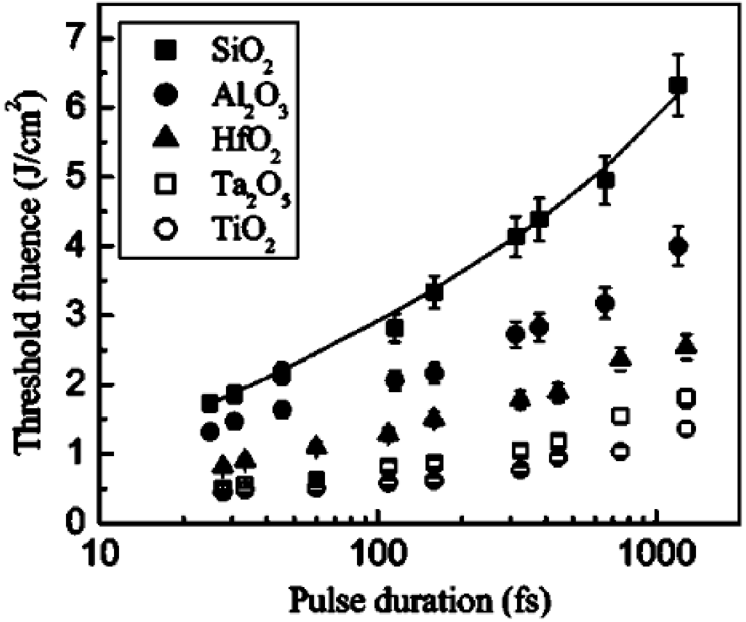
DANGEROUS!!!

- Only valid if no other influencing factors are changed

  => unlikely to happen, do not rely on that!

Scaling laws: fs regime

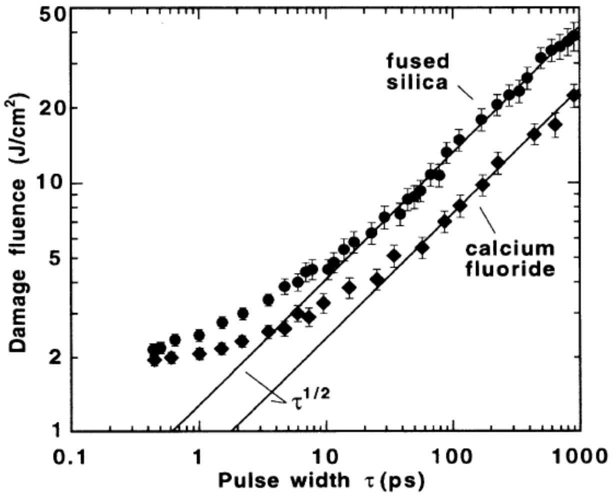
- LIDT ~ $E_{gap}\ \tau^{0.3}$ (Mero et al. 2005)



- High rep-rate in common fs lasers can lead to thermal quasi-cw damage
- Non-linear effects (mainly self-focussing) may trigger bulk damage

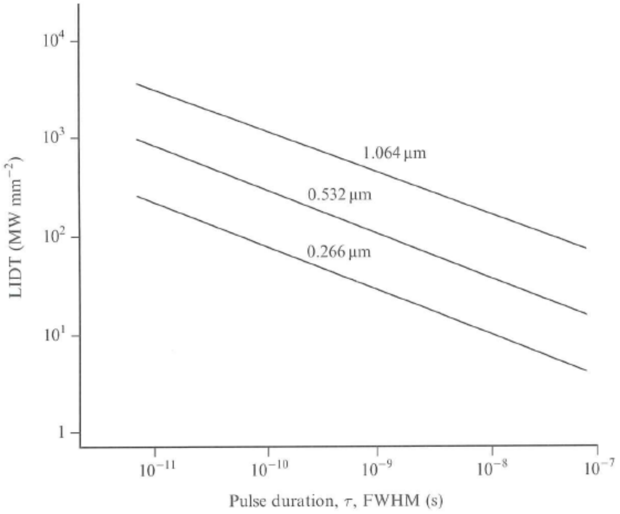
Scaling laws: ns regime

- LIDT $\sim \tau^{1/2}$ (Wood, 1986)



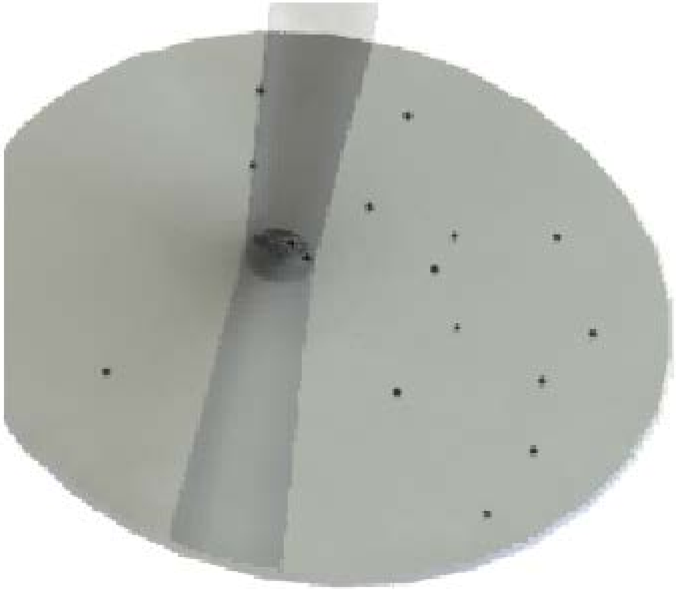
Stuart et. al. (1994)

- LIDT $\sim \lambda^{1/2}$ (Wood, 2003)

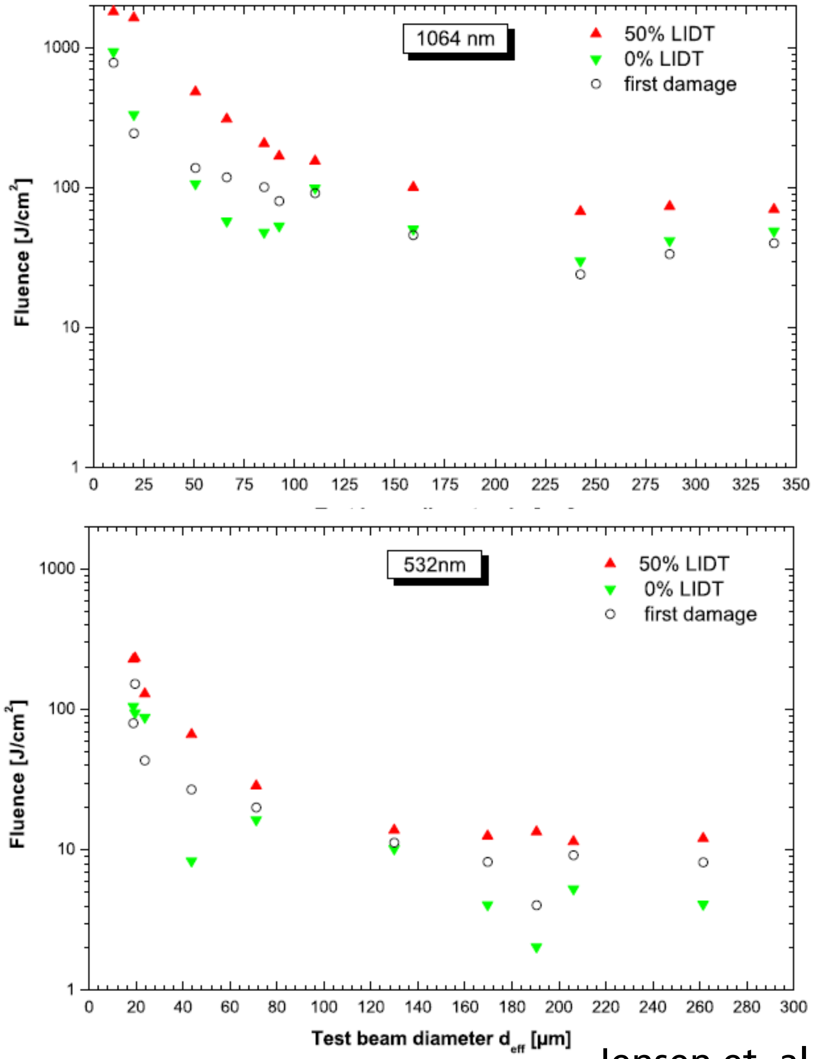


Wood (2003)

Influencing Factors: Beam Diameter



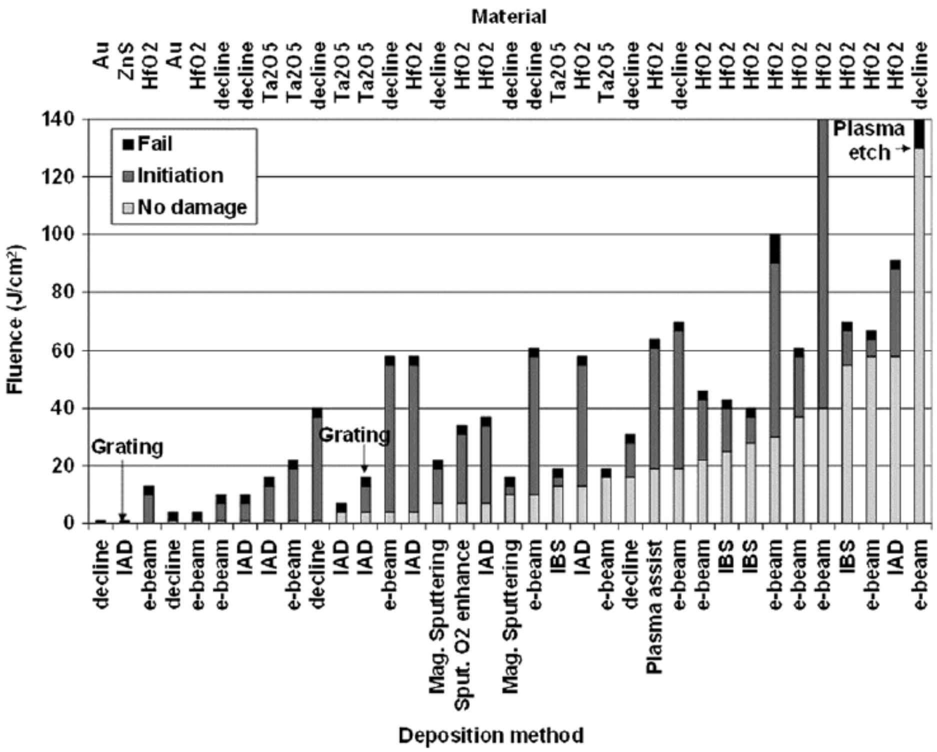
Jensen et. al. (2009)



Jensen et. al. (2009)

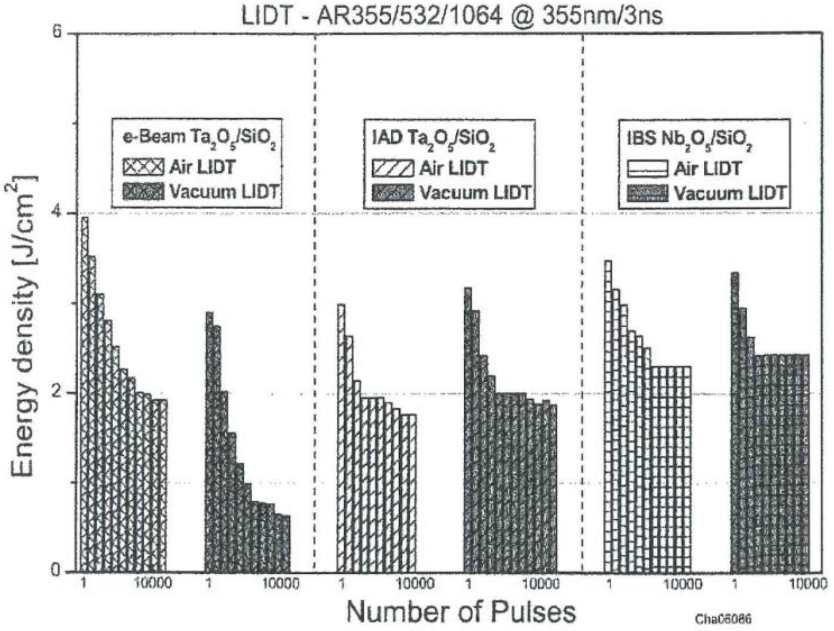
Influencing Factors: Prod. Method and Material

HR(>99.5%, 0°) 1064 nm, 5 ns, 10 Hz



Stolz, Opt. Eng. 51(12), 2012

Influencing Factors: Vacuum Effect



Jensen et. al. (2006)

Can be attributed to water content in coating,
Hypothesis: heat conduction reduction
increased mechanical stress

Influencing Factors

- Laser beam parameters (obviously…)
- Coating and substrate materials
- Coating design
- Atmosphere
- Number of shots
- Polishing
- Cleanliness
- …

=> If you want to be sure about LIDT: **Test your special case!**

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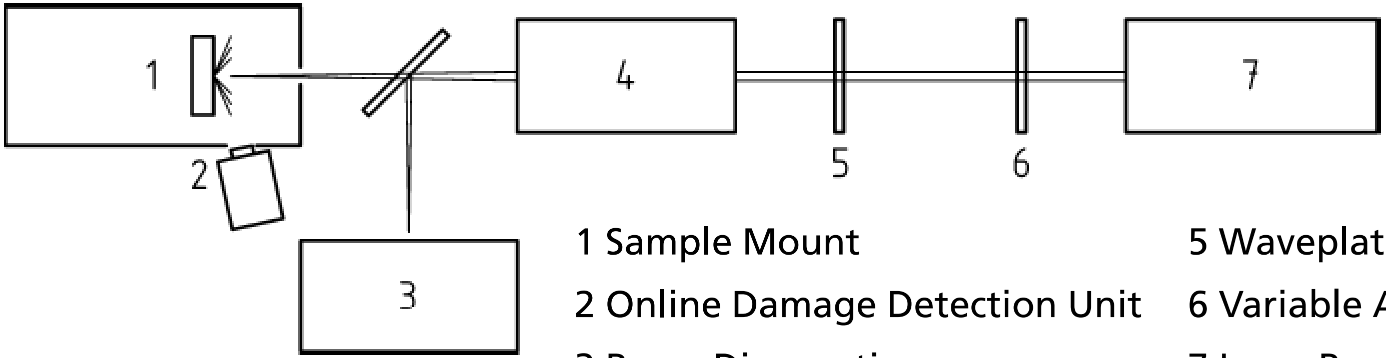
LIDT-Testing: DIN-ISO 11254-2

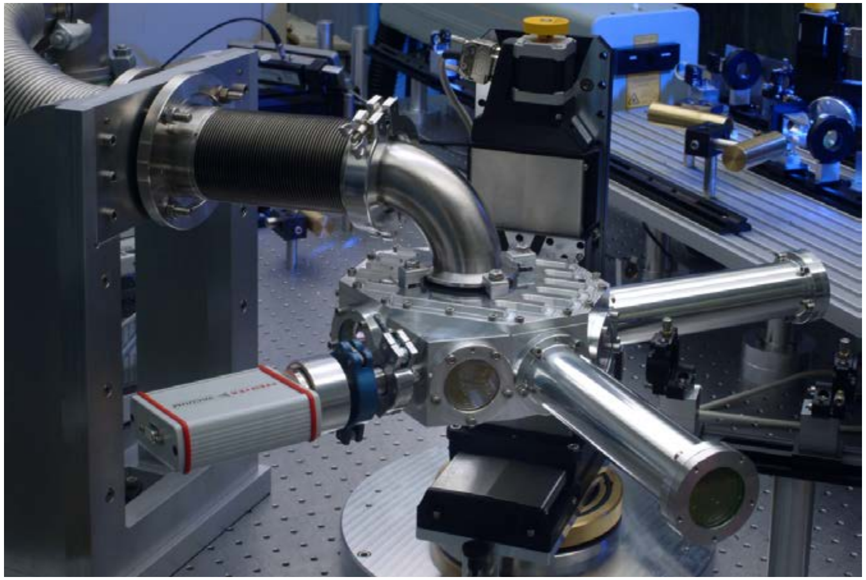


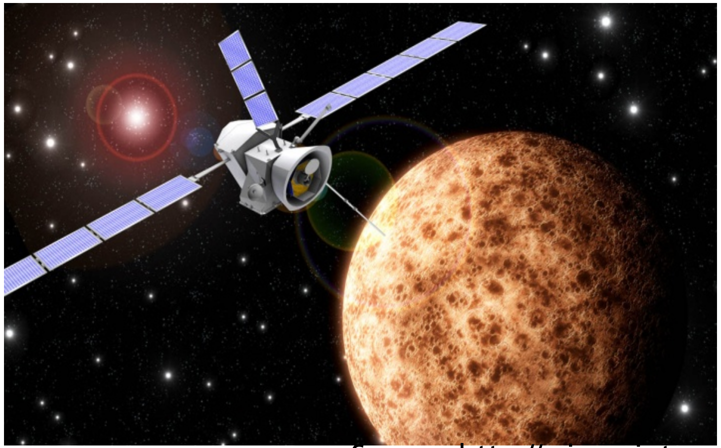
1 Sample Mount
2 Online Damage Detection Unit
3 Beam Diagonstics
4 Beam Shaping Unit
5 Waveplate
6 Variable Attenuation Unit
7 Laser Beam Source

- One test spot: just one energy density and one maximal number of pulses
- Multiple test spots on one sample -> statistics!
- Avoid contamination of other test spots with debris from induced damages
- Use large beam diameters (at least 800 µm diameter suggested)

LIDT-Testing: ILT Test Station

- Compliant with ISO 11254-2
- Semi-automated procedure
- Test sample environment can be defined:
  $p < 10^{-5}$ mbar or gas purging
- Successfully used for flight item qualification of ESA's BepiColombo Laser Altimeter
- 1064 nm, 5 ns, 30 Hz
- > 160 J/cm^2 with
  800 µm beam diameter
- Currently being rebuilt:
  1645 nm, 20 ns, 100 Hz (MERLIN)





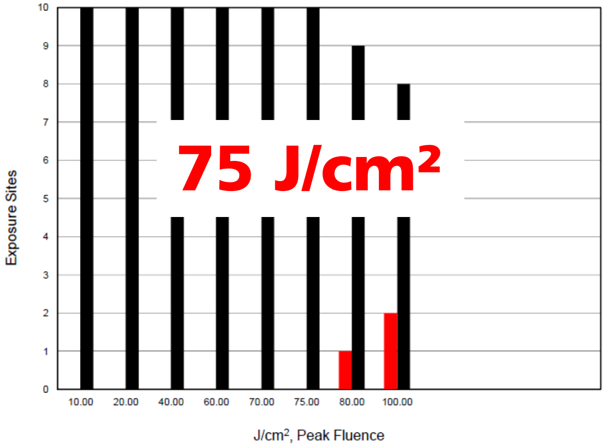
Source: http://sci.esa.int

LIDT-Testing

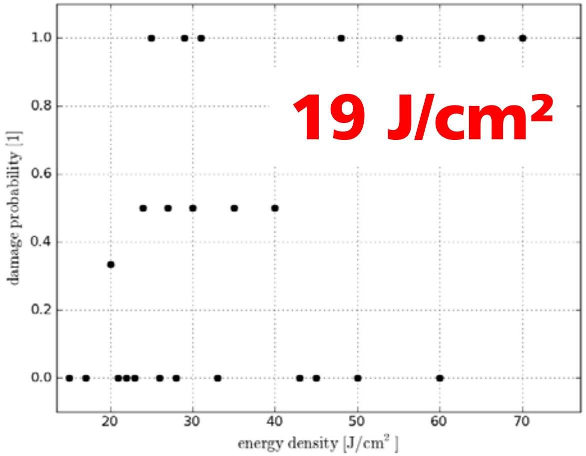
tested at contractor:
50 µm, 100 Hz, 20 ns

tested at ILT:
800 µm, 30 Hz, 5 ns

HR 1064 nm, 0°

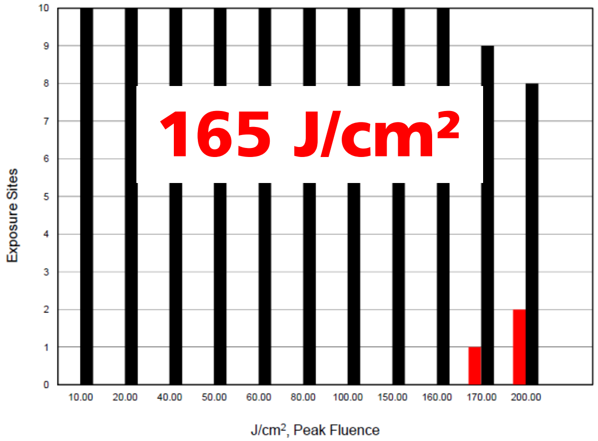


75 J/cm^2

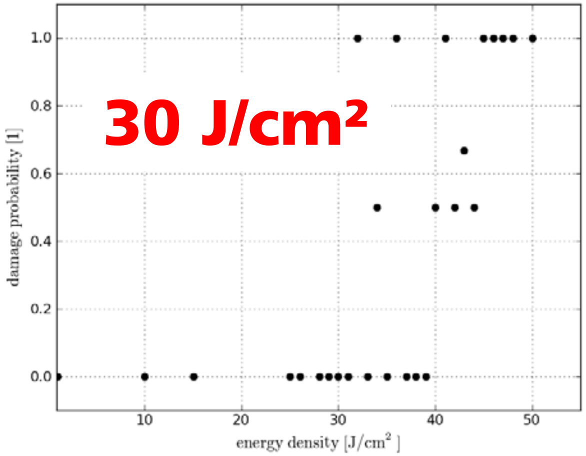


19 J/cm^2

Thin Film Pol.
1064 nm, 56 °



165 J/cm^2



30 J/cm^2

Take-Away Messages

- Be aware of LIDT: Do you need to pay attention?
- Always specify your application case to optics supplier!
- Laser damage is highly statistical and depends on just about everything
  - Be sceptical with generalization of results!
  - Scaling laws are no more than rules of thumb!
  - If supplier specifies LIDT for optical component: Ask for test conditions/parameters (rep rate, pulse duration, wavelength, beam diameter, number of pulses,…)
- If LIDT is critical -> Test it!!
- Be critical with applicability of LIDT test results