Laser-induced damage in optical components for high-power infrared laser systems

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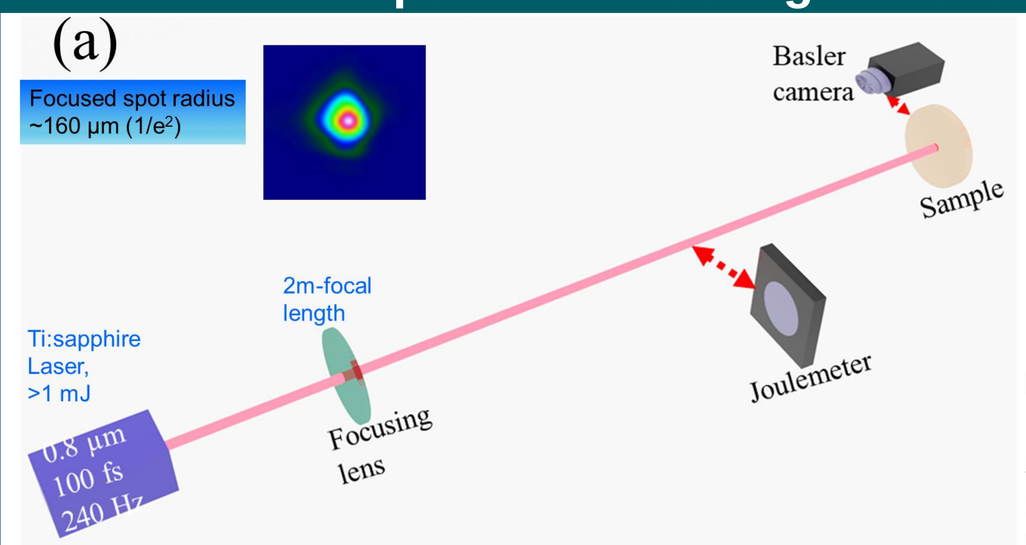
Motivation

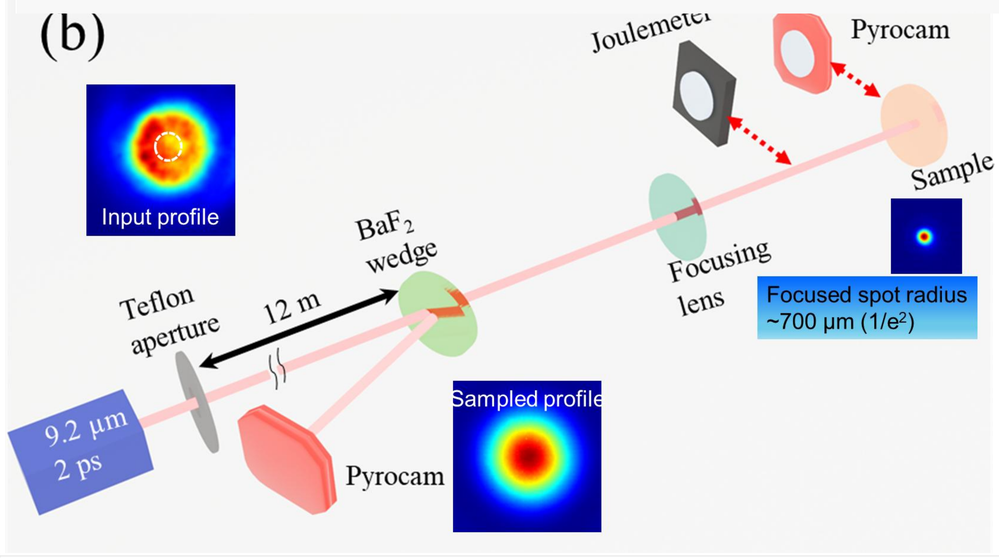
Accurate measurement of laser-induced damage threshold (LIDT) is essential for designing reliable optics in next-generation laser-driven accelerator systems. Despite ISO-based standard tests data, consistent LIDT data across near-infrared (NIR) to the long-wave infrared (LWIR) are scarce. We report LIDT measurements for a broad set of optical components, comparing experiments with theoretical frameworks based on Keldysh strong-field ionization theory and the Gamaly ablation model, revealing a transition from multiphoton-dominated NIR photoionization to tunneling-assisted LWIR ionization. These results inform component selection and risk-reduction strategies for high-power laser systems.

Experimental configurations



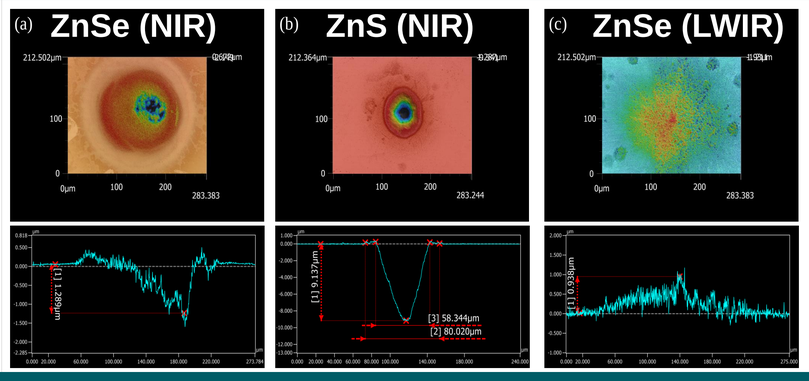
NIR: 0.8 μm, 100 fs, 240 Hz

Beam profiles were monitored near the sample plane: Basler camera for NIR and Pyrocam IV for LWIR.



LWIR: 9.2 μm, 2 ps, single-shot

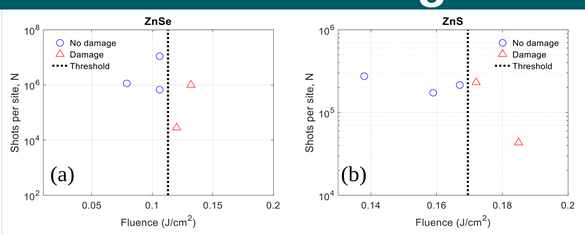
Damage morphology

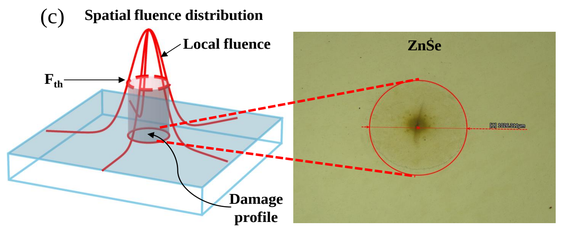


Representative NIR and LWIR damage morphology: surface response differs strongly with material and wavelength (deeper crater in ZnS for NIR).

Repeated pulses in multi-shot cause further material removal compared to single-shot exposure.

Damage threshold measurement





NIR: multi-shot sites classified as damage / no damage.
Damage is initiated by a single shot and the subsequent shots contribute to crater expansion. Damage threshold is interpreted as single-shot.

LWIR: single-shot threshold inferred from damage-boundary fluence.

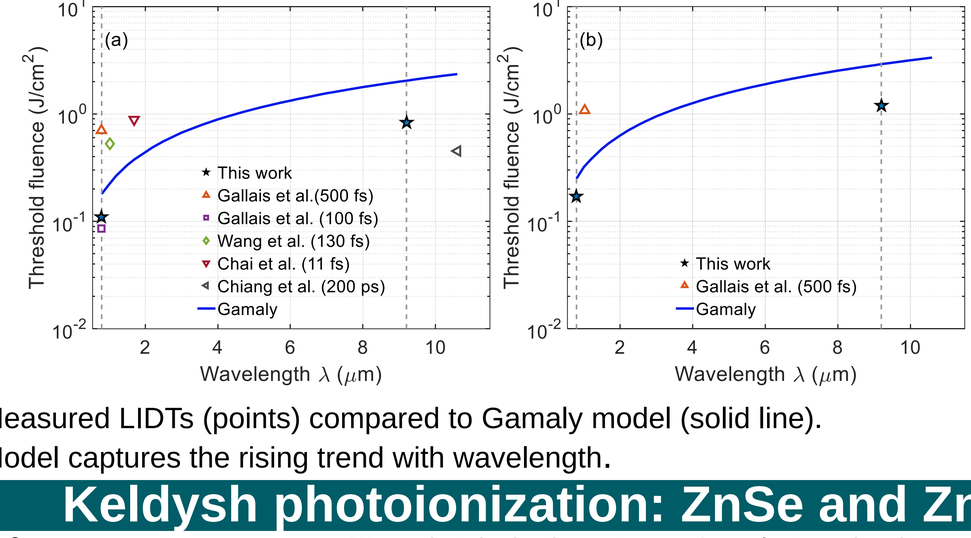
Reported thresholds use spatial fluence distribution at the sample.

Measured threshold results

	λ (μm)	Measured LIDT (J/cm²)	Model LIDT (J/cm²)
ZnSe	0.8	0.112	0.18
	9.2	0.83	2.04
ZnS	0.8	0.170	0.25
	9.2	1.19	2.91
Au	0.8	*0.45 (Lit.)*	0.50
	9.2	3.6	4.4
Cu	0.8	*0.5-0.6 (Lit.)*	0.51
	9.2	4.3	5.7

Gamaly model comparison: ZnSe and ZnS

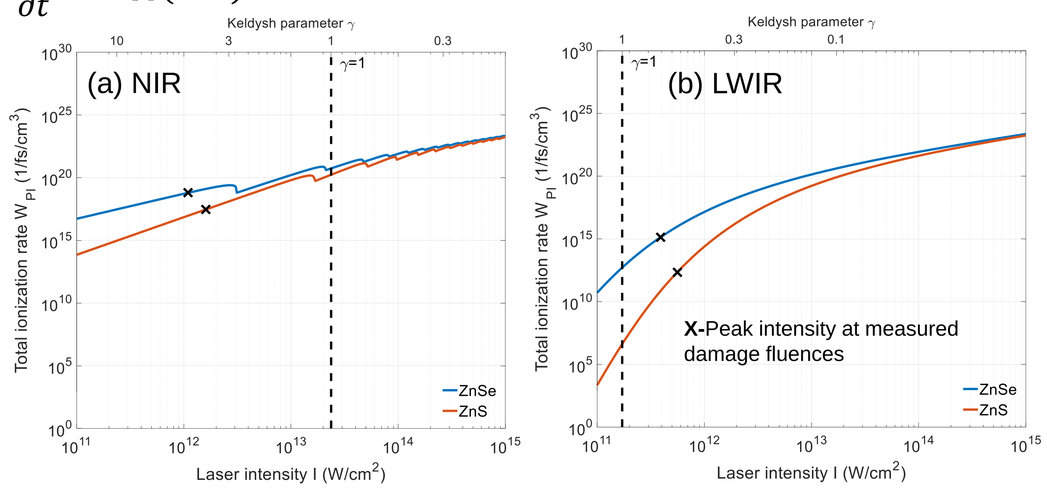
Dielectrics: $F_{th} = (3n_a\lambda/16\pi)(\epsilon_b + E_g)$ n_a = Valence band density ϵ_b = Binding energy E_g = Band gap



Measured LIDTs (points) compared to Gamaly model (solid line).
Model captures the rising trend with wavelength.

Keldysh photoionization: ZnSe and ZnS

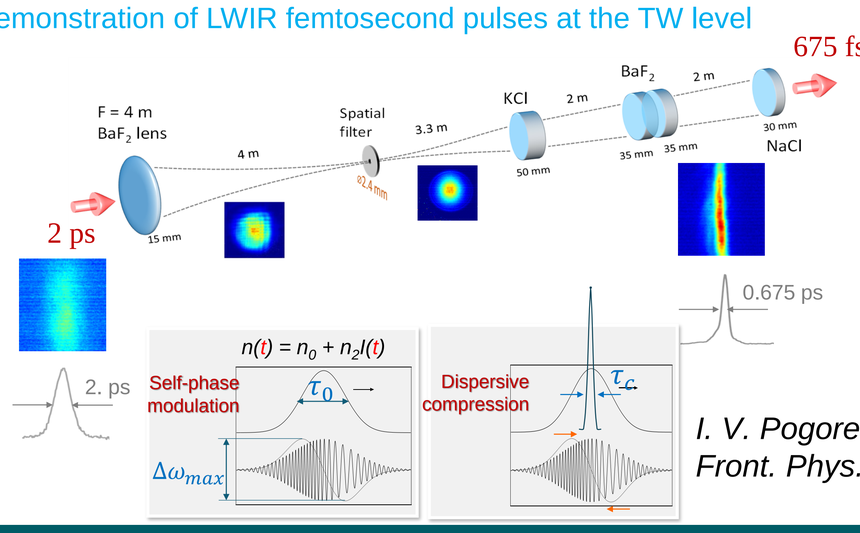
$\frac{\partial n_e}{\partial t} = W_{PI}(I(t))$ W_{PI} =photoionization rate, n_e =free electron density, $I(t)$ =instantaneous laser intensity



Photoionization rates as a function of laser intensity calculated using Keldysh theory.
Difference in damage thresholds is attributed to the material's band gap.

Applications: CO_2 laser Post-compression

First demonstration of LWIR femtosecond pulses at the TW level



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Conclusions

- ✓ *ZnSe and ZnS exhibit an order-of-magnitude higher short-pulse LIDT in the LWIR compared to the NIR.*
- ✓ *The increase follows Gamaly model predictions and is explained by a transition from multiphoton to tunneling-dominated ionization.*

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