Material fracture by focusing of laser-generated surface acoustic waves

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Forum ILP, June 13, 2018

Acknowledgments (1/2)

Experiments:
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Alexei A. Maznev (MIT),
Yevheniia Chernukha (Université du Maine),
Dmitro Martynowich (MIT),
Keiichi Nakagawa (MIT),
Alexey M. Lomonosov (Prokhorov General Physics Institute RAS),
Thomas Pezeril (Université du Maine),
Keith A. Nelson (MIT).

Simulations:
Ryadh Haferssas (MIT),
Mostafa Hassani-Gangaraj (MIT),
Mohammad Islam (MIT),
Christopher A. Schuh (MIT),
Raul Radovitzky (MIT).

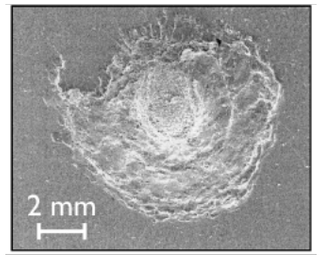
Sample fabrication:
Xiaoguang Zhao (Boston University),
Xin Zhang (Boston University).

Motivations

- Study high-strain-rate material failure through *real-time* obvervations

  Today: thin-metallic film on glass and glass

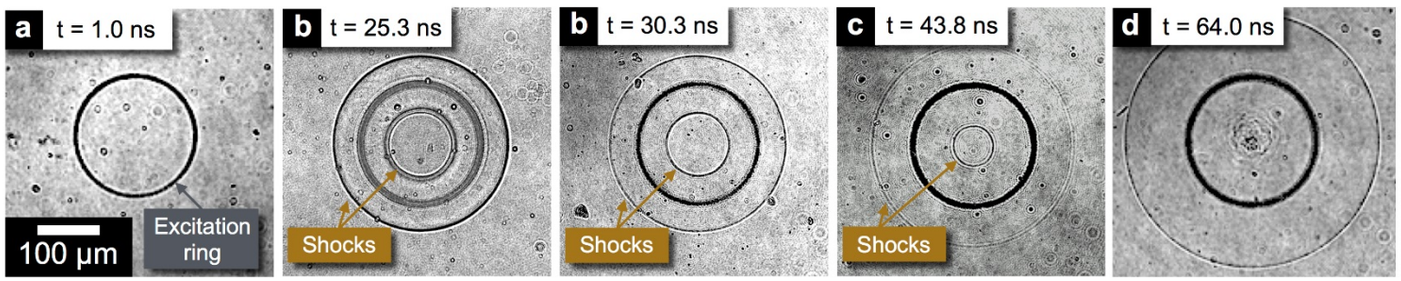
  cf Jean-Pierre Guin's talk yesterday

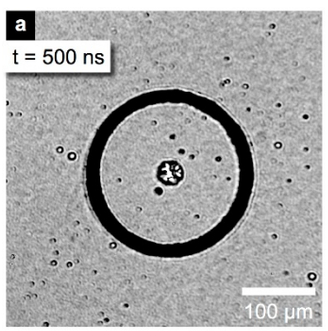


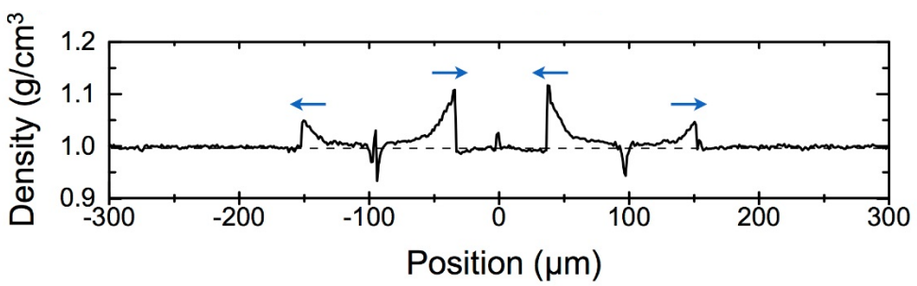
- Reach high amplitude through *focusing* of surface acoustic wave (SAW) at the micron scale

- Apply diagnostic methods developed to study focusing shock wave to SAW

In water



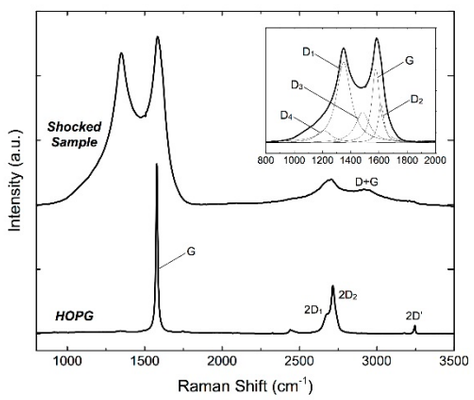


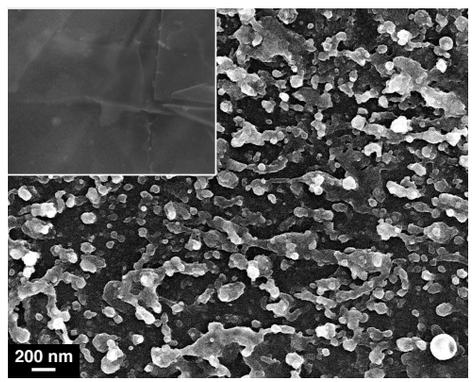


Pezeril T, Saini G, Veysset D, Kooi S, Fidkowski P, Radovitzky R, Nelson KA. Phys Rev Lett 2011;106:214503.

In graphite

$sp^2 \rightarrow sp^3$ transformation





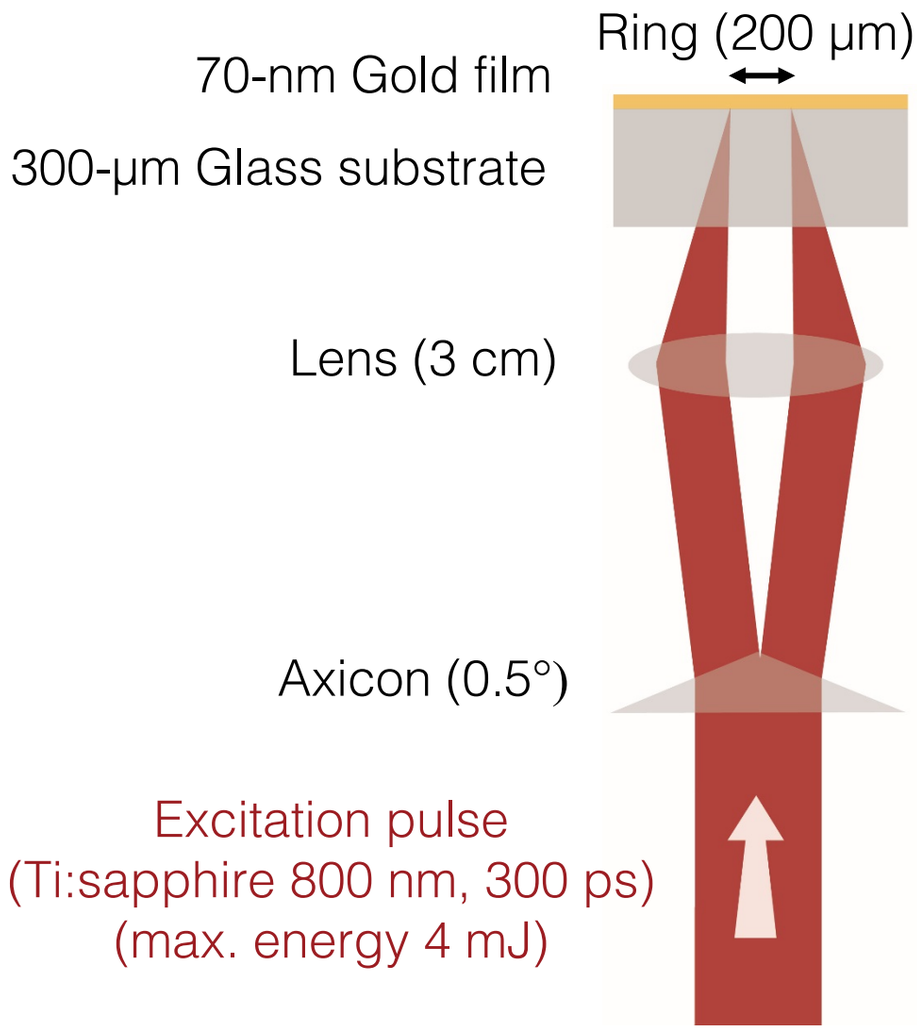
Veysset D, Pezeril T, Kooi S, Bulou A, Nelson KA. Appl Phys Lett 2015;106:161902.

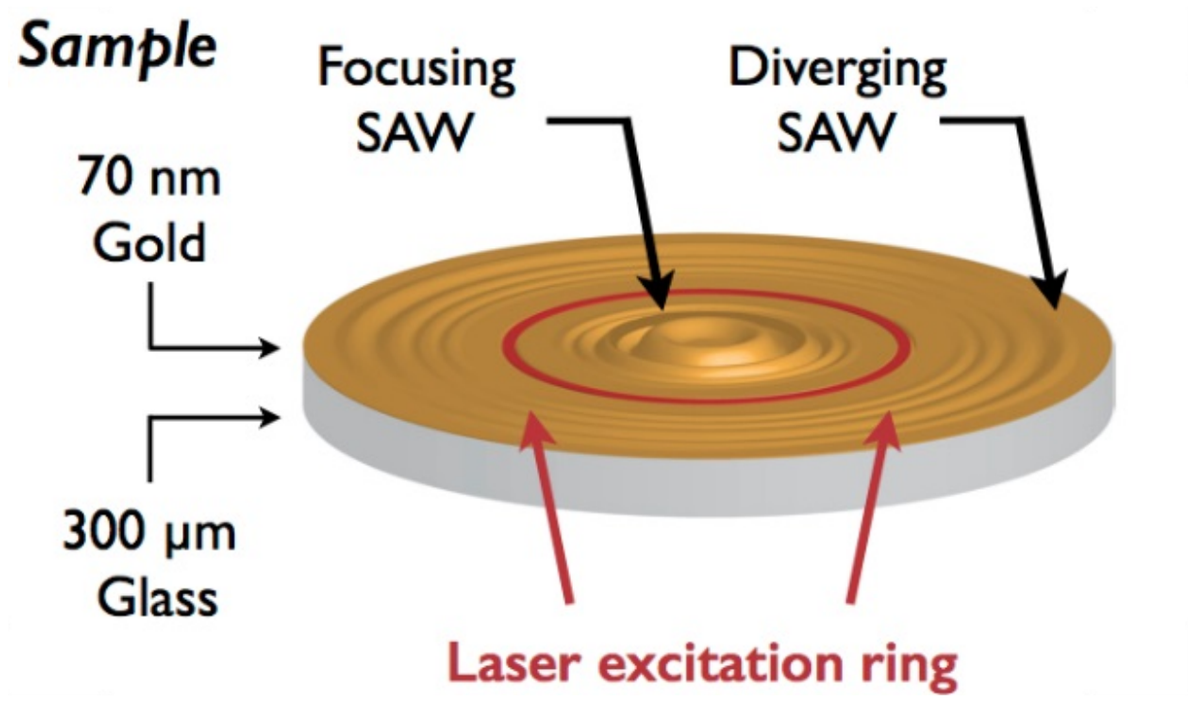
Outline

- Thin film delamination and fracture via large amplitude SAW
- Glass strength and fracture

Laser-generated focusing surface acoustic waves (SAW)

The laser focus shaped as a **ring** using a conical prism (axicon):
("rond de serviette" or "donut")

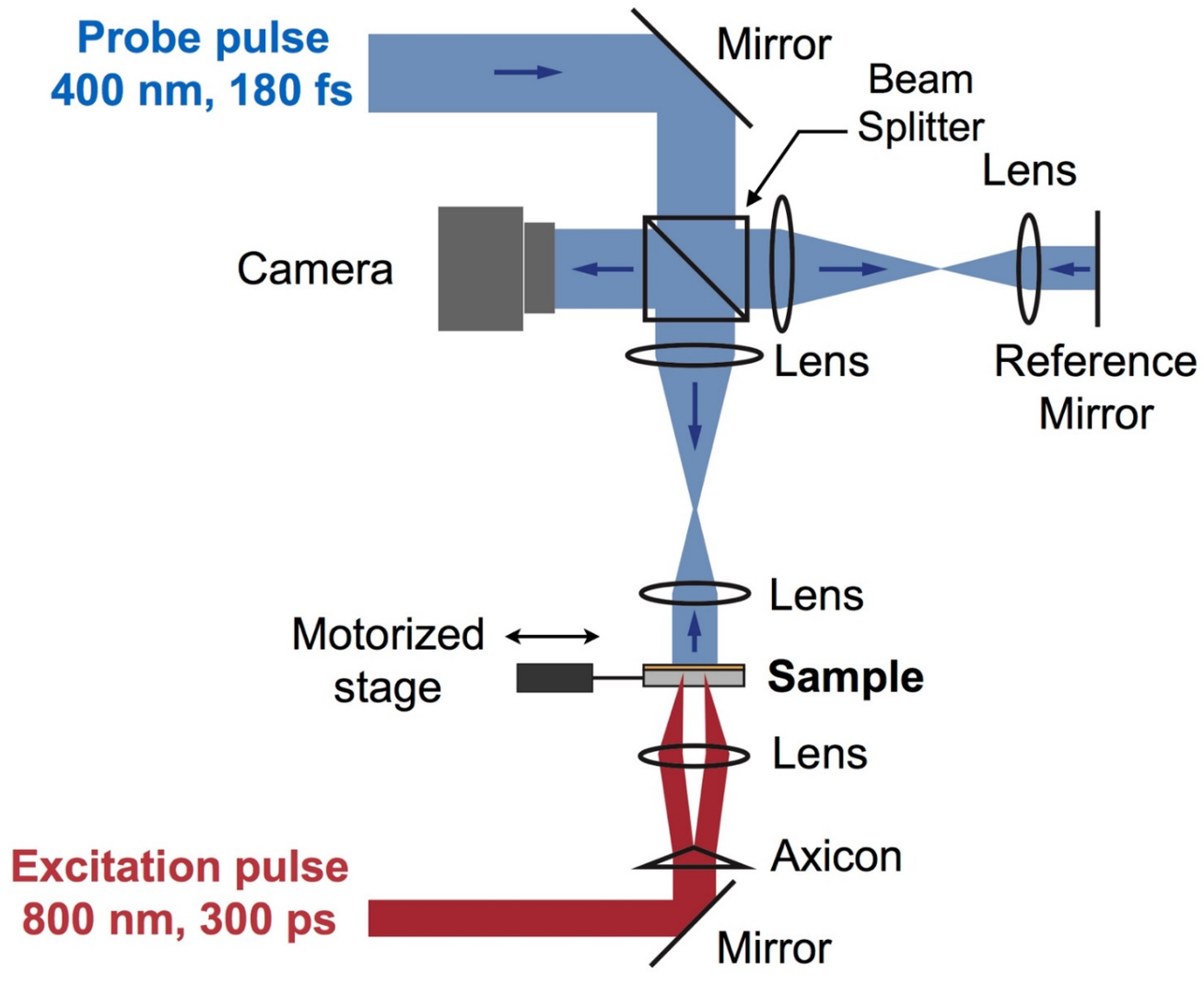


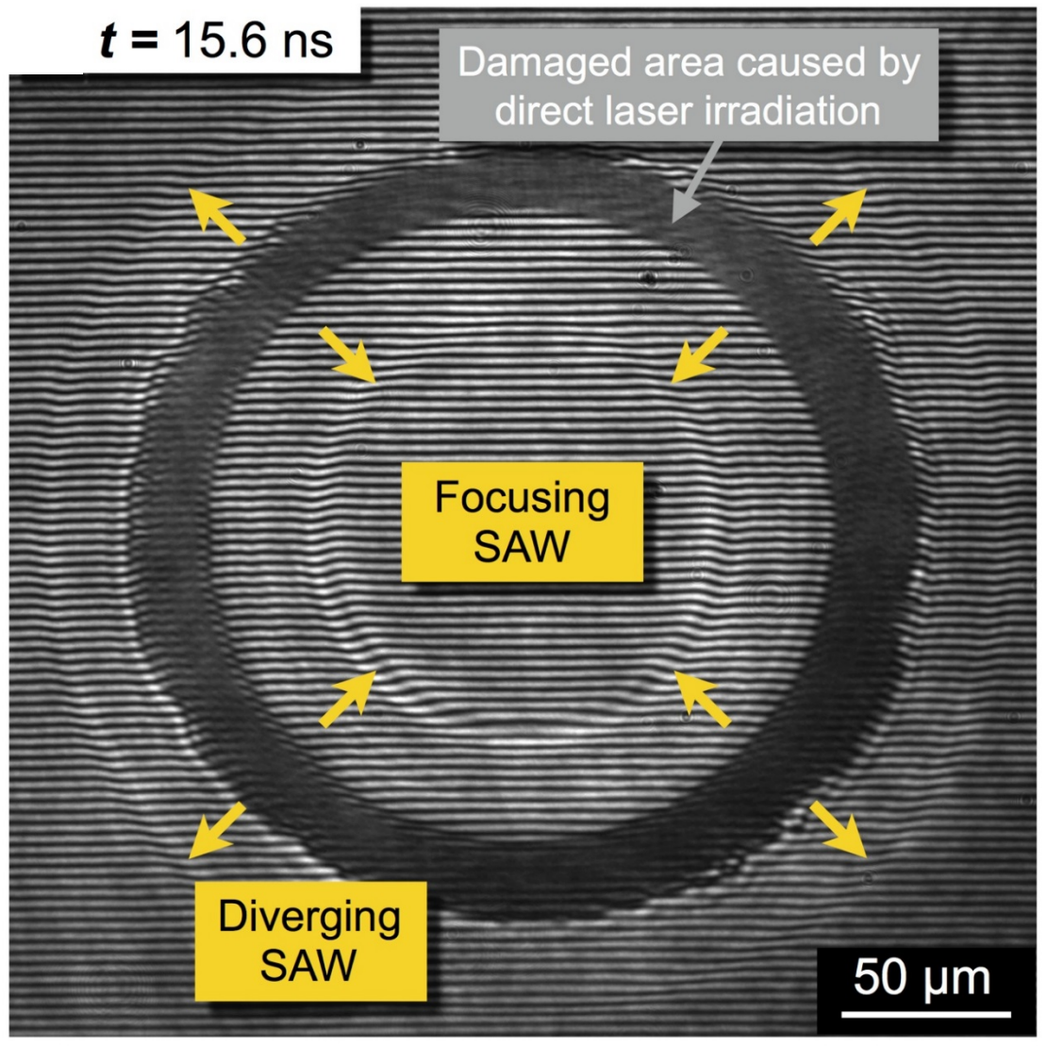


D. Veysset, A.A. Maznev, I.A. Veres, T. Pezeril, S.E. Kooi, A.M. Lomonosov, K.A. Nelson, Appl. Phys. Lett. 111 (2017) 31901.

Full-field interferometric imaging of SAW

Allows the quantitative measurement of the surface displacements.

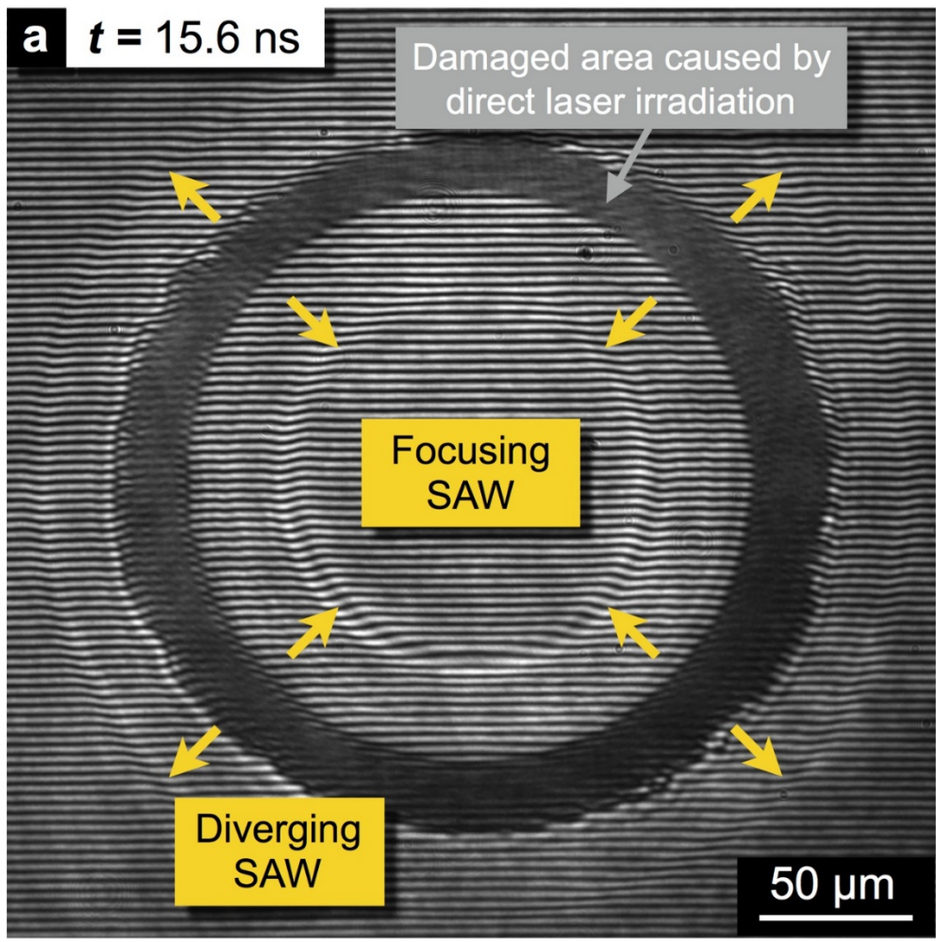


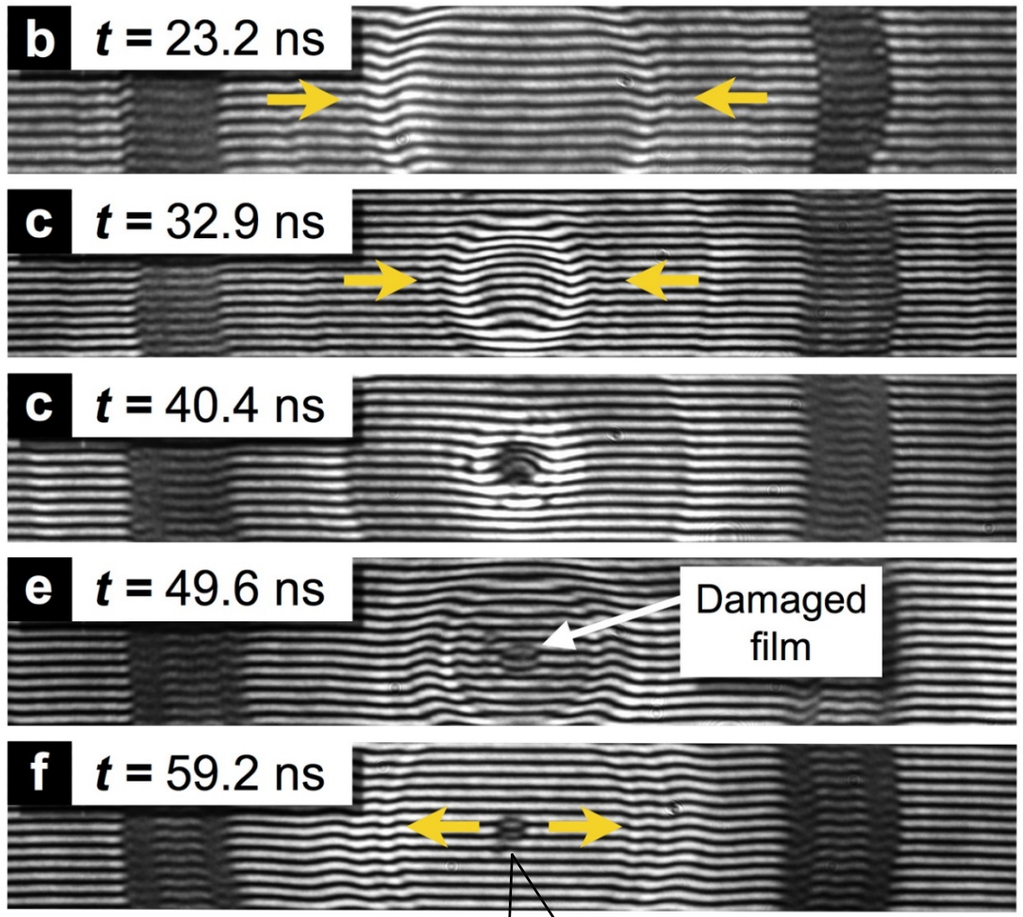


Laser energy: 0.2 mJ
Fluence: 3.2 J/cm^2

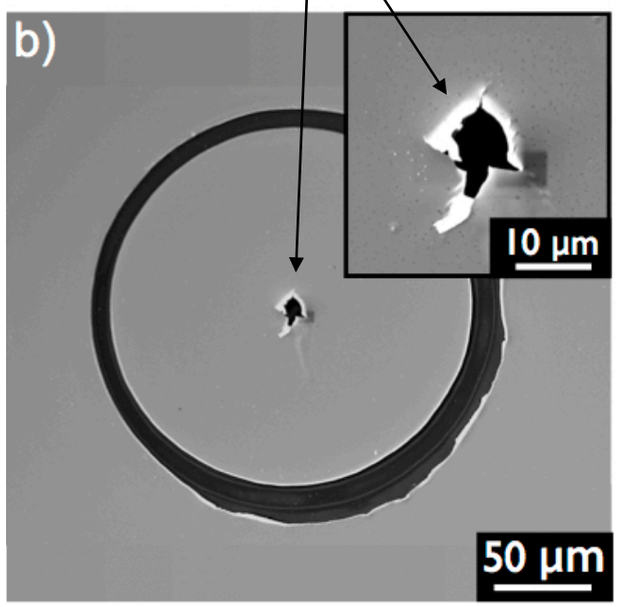
D. Veysset, A.A. Maznev, I.A. Veres, T. Pezeril, S.E. Kooi, A.M. Lomonosov, K.A. Nelson, Appl. Phys. Lett. 111 (2017) 31901.

Gold film damage upon SAW focusing





SEM examination



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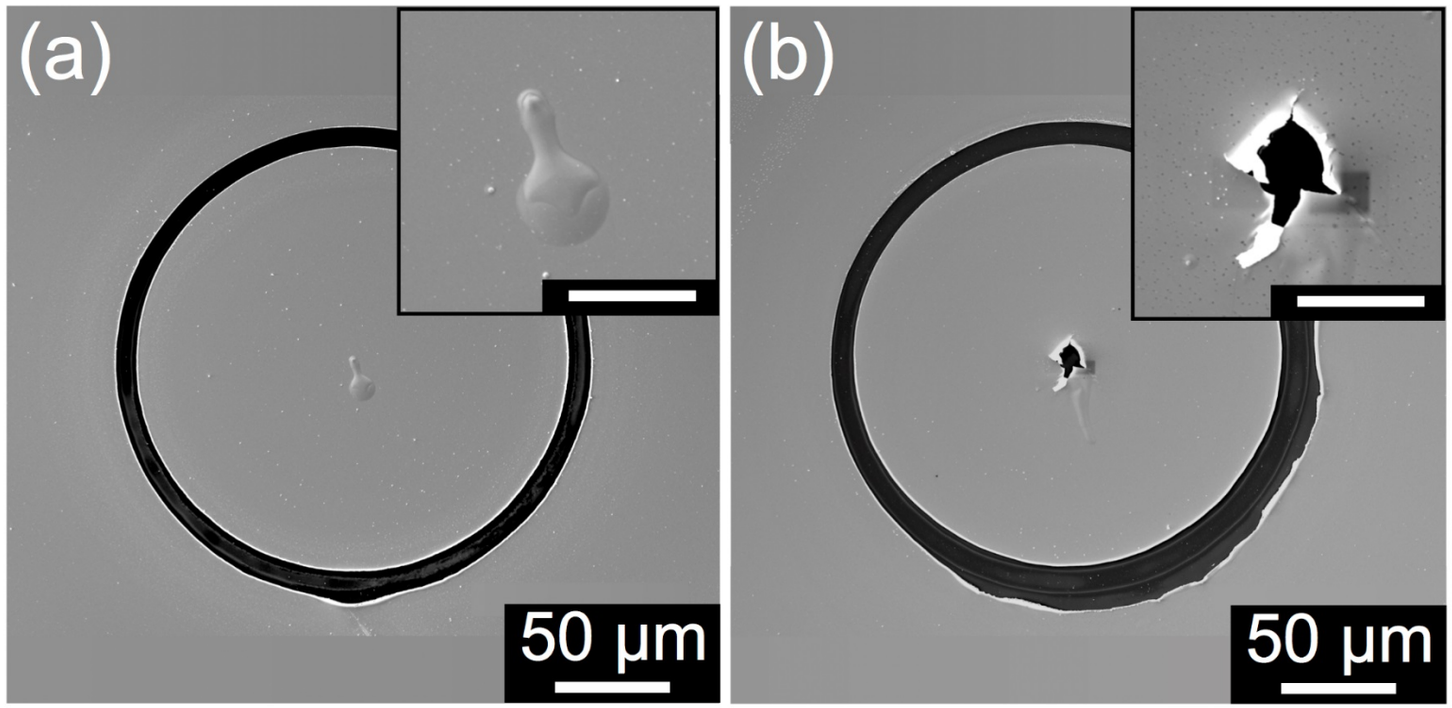
Material damage vs laser energy

Examination under scanning electron microscope

Laser energy: 0.1 mJ
Fluence: 1.6 J/cm^2

Laser energy: 0.2 mJ
Fluence: 3.2 J/cm^2



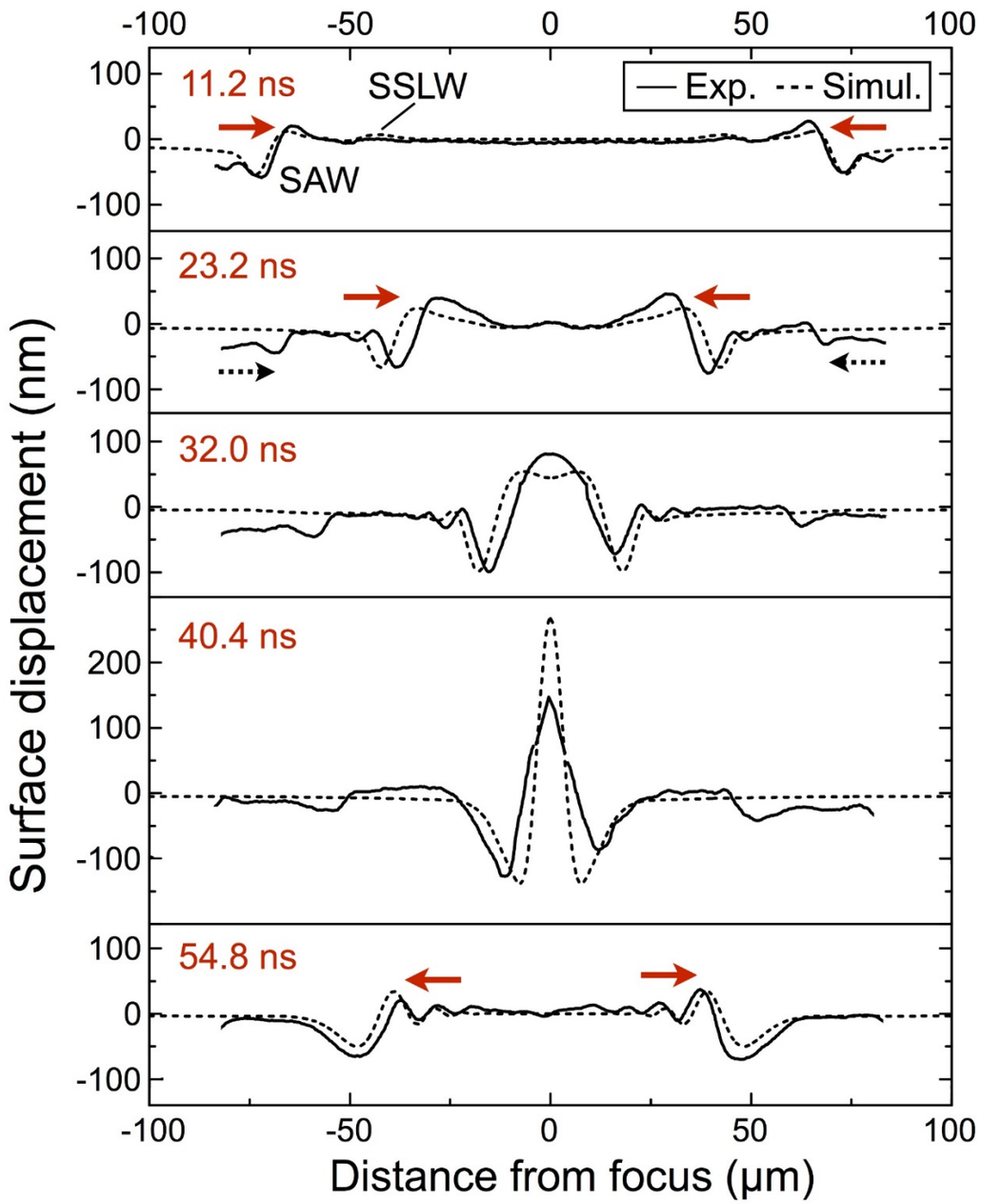
Gold film delamination

Film rupture

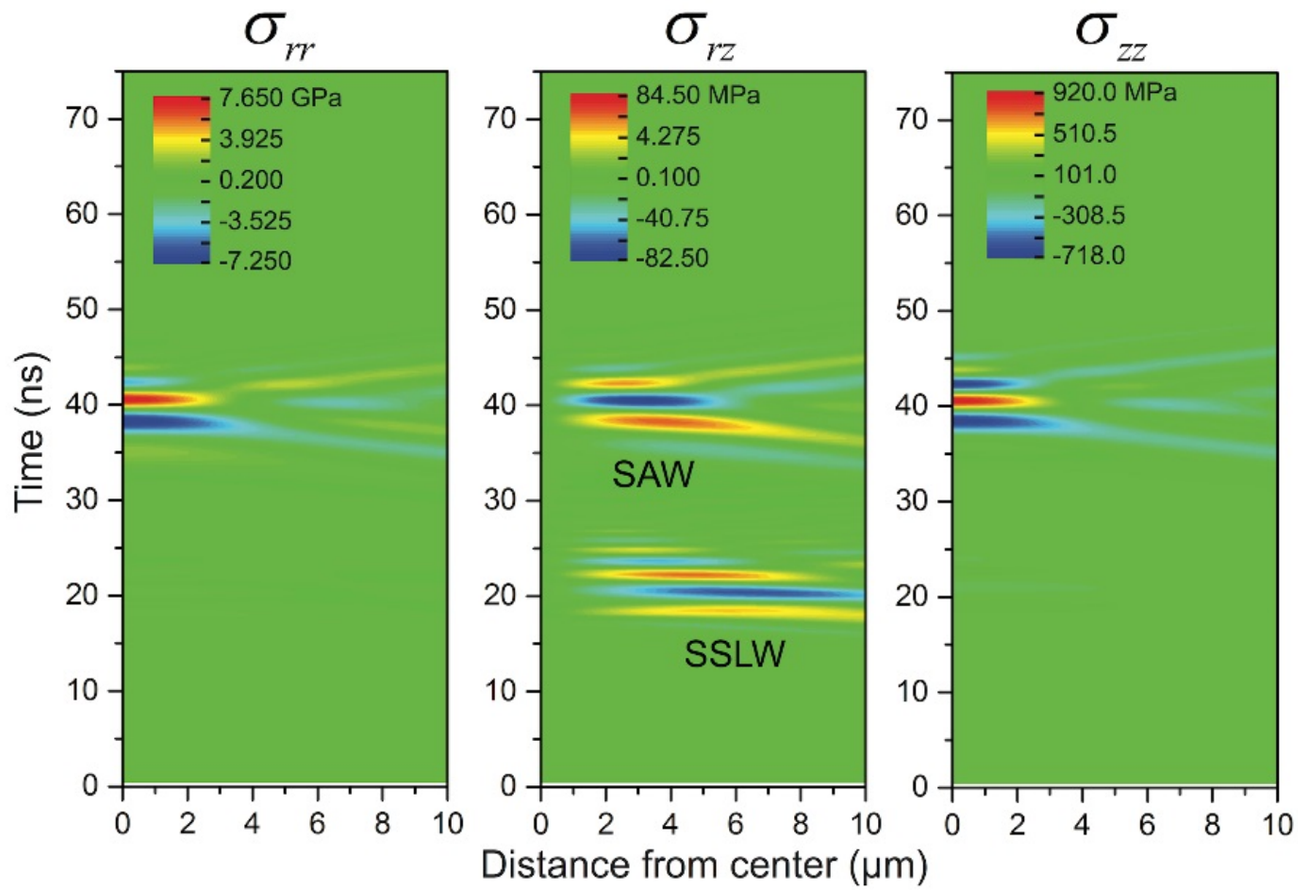
Stresses??

Surface displacements: experiments vs. simulations

— Experimental
····· Simulation (**linear**)



Corresponding stresses at the gold film interface (70 nm)



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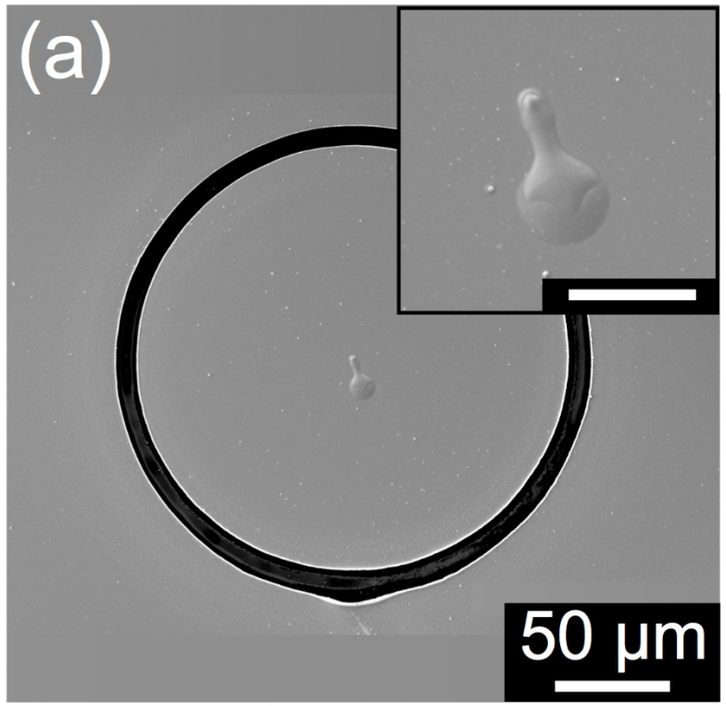
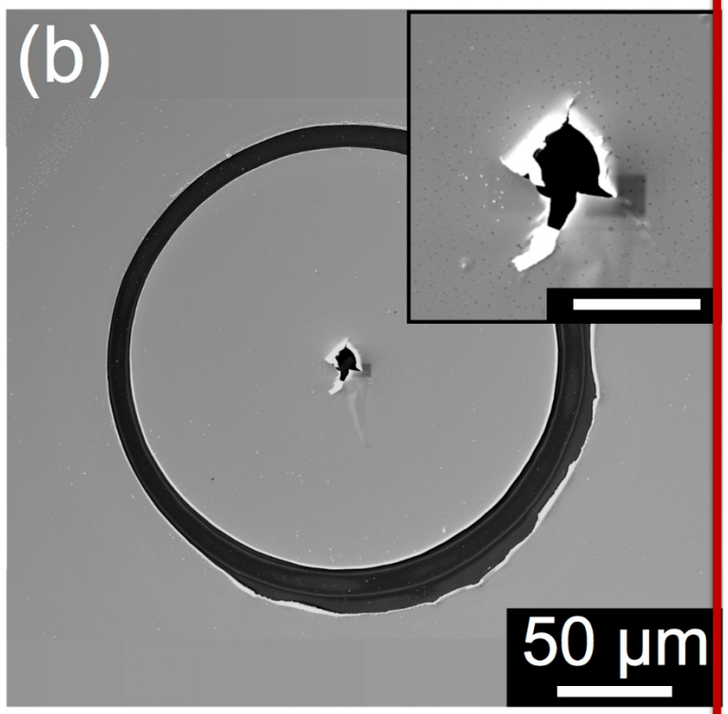


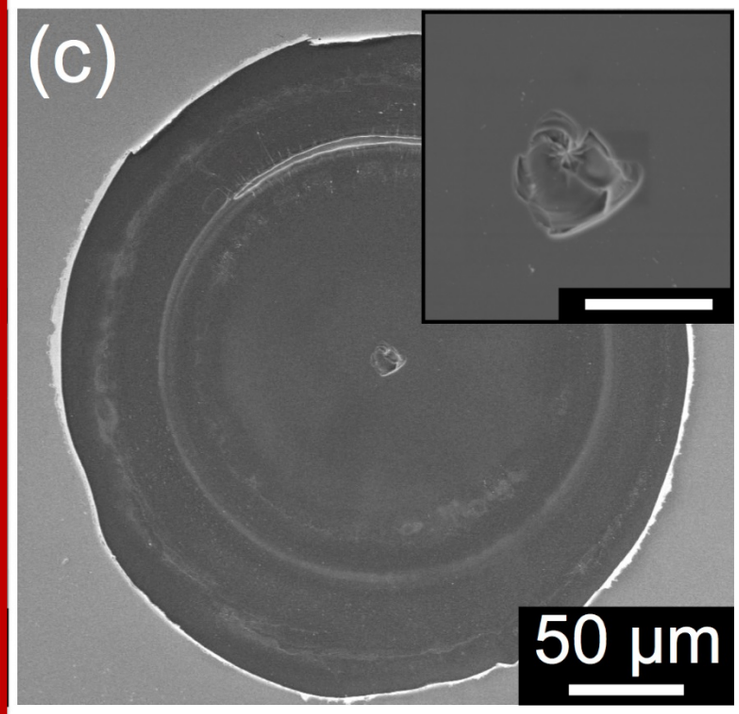
Gold film delamination

Laser energy: 0.2 mJ
Fluence: 3.2 J/cm^2



Film rupture

Laser energy: 2.4 mJ
Fluence: 38.1 J/cm^2



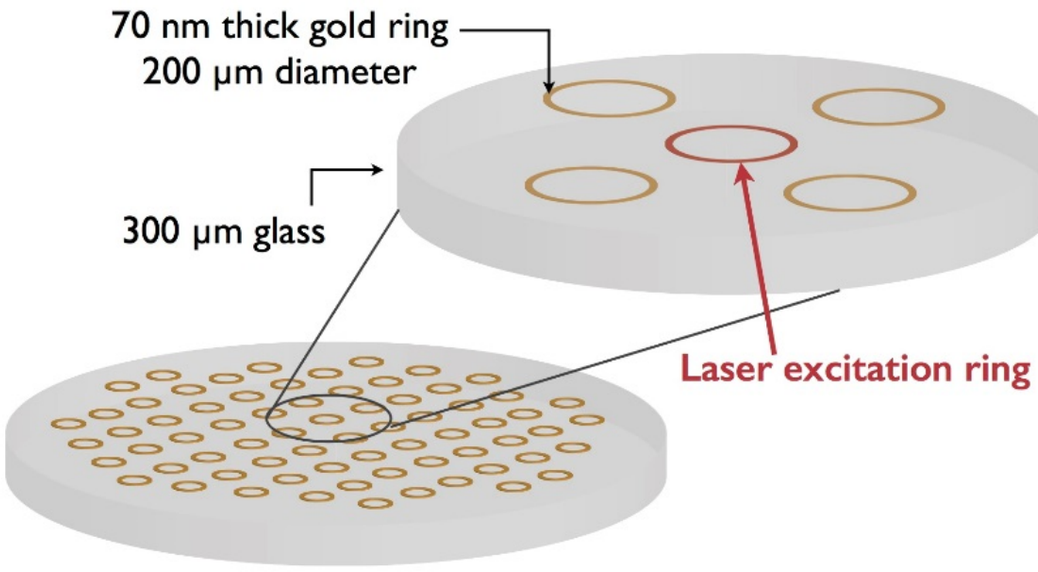
Glass substrate damage
Stresses??

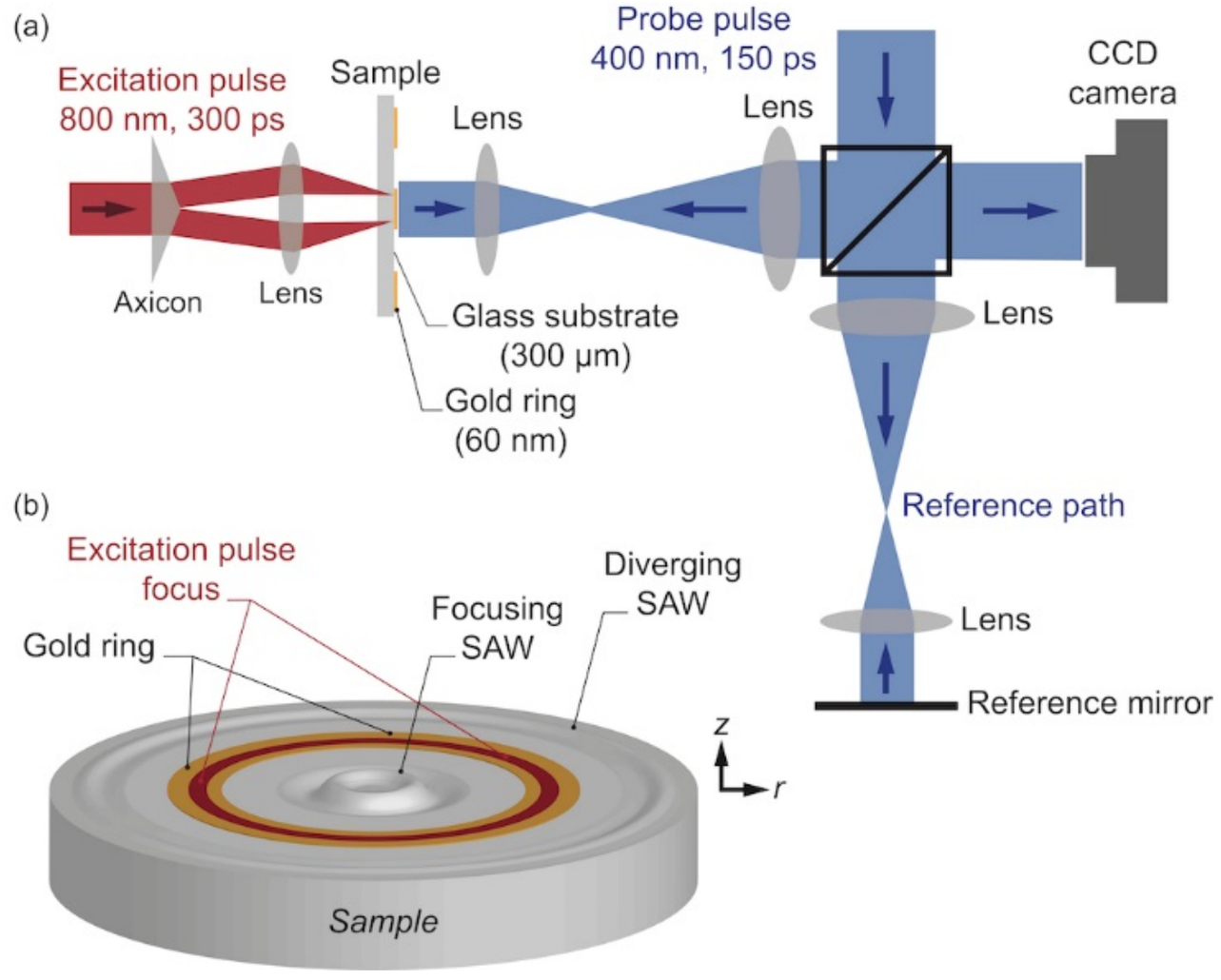
Gold film delamination prevents surface displacement measurements at high laser energies

Solution: using gold rings instead of uniform coating

SAW propagation on bare glass

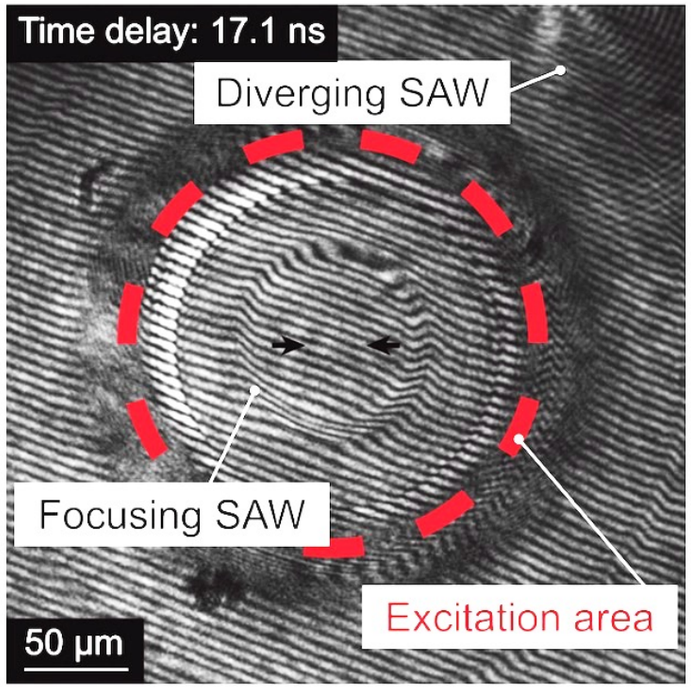
Same optical setup and image analysis procedure
to extract SAW normal displacements.

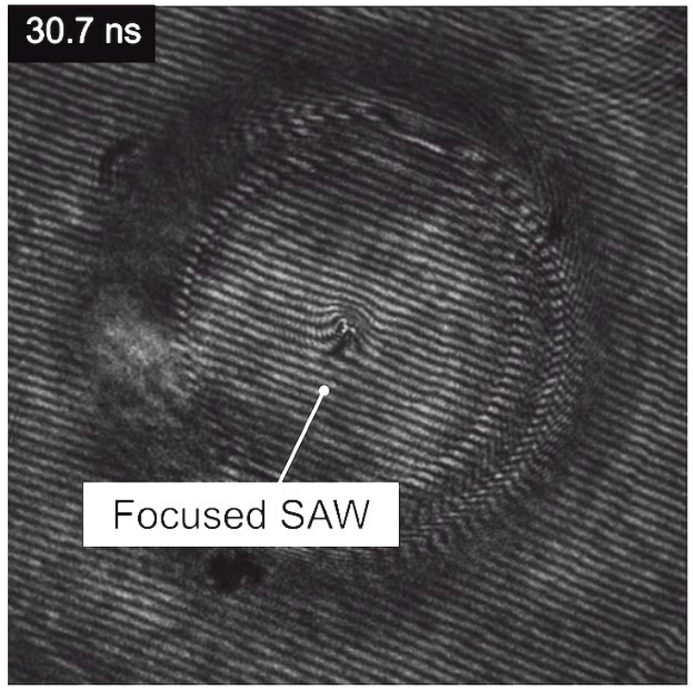


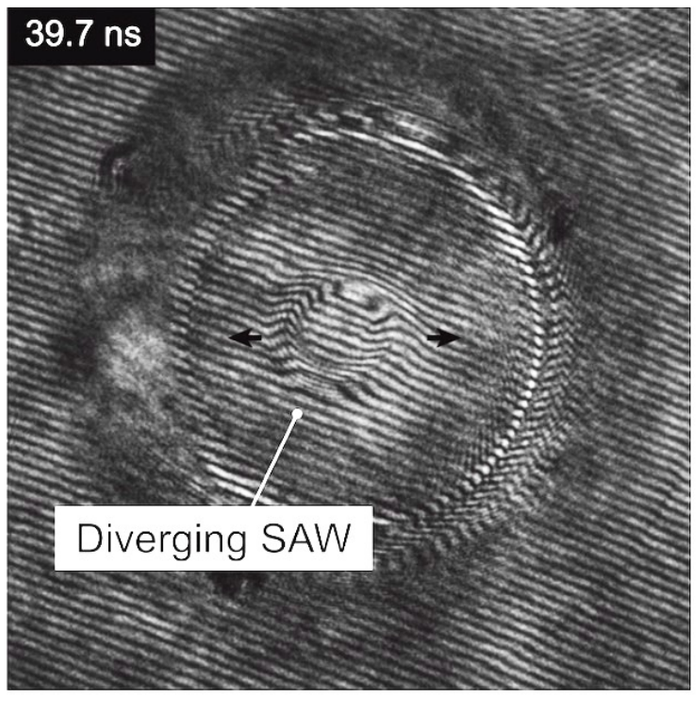


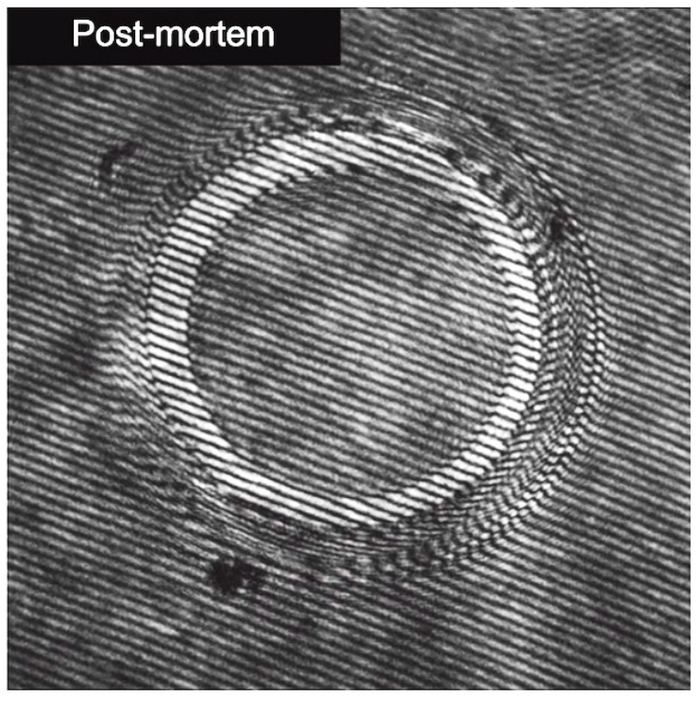
Time-resolved interferometric images

E_{Laser} = 0.25 mJ

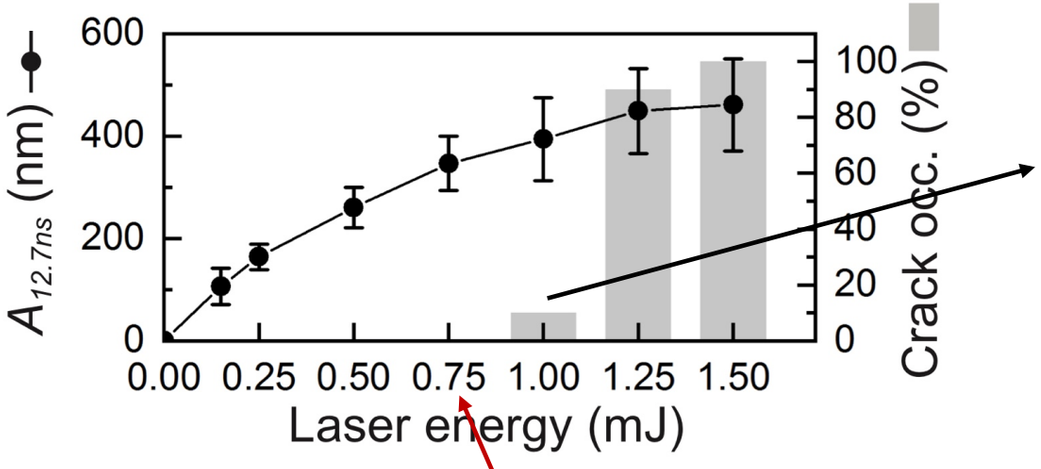








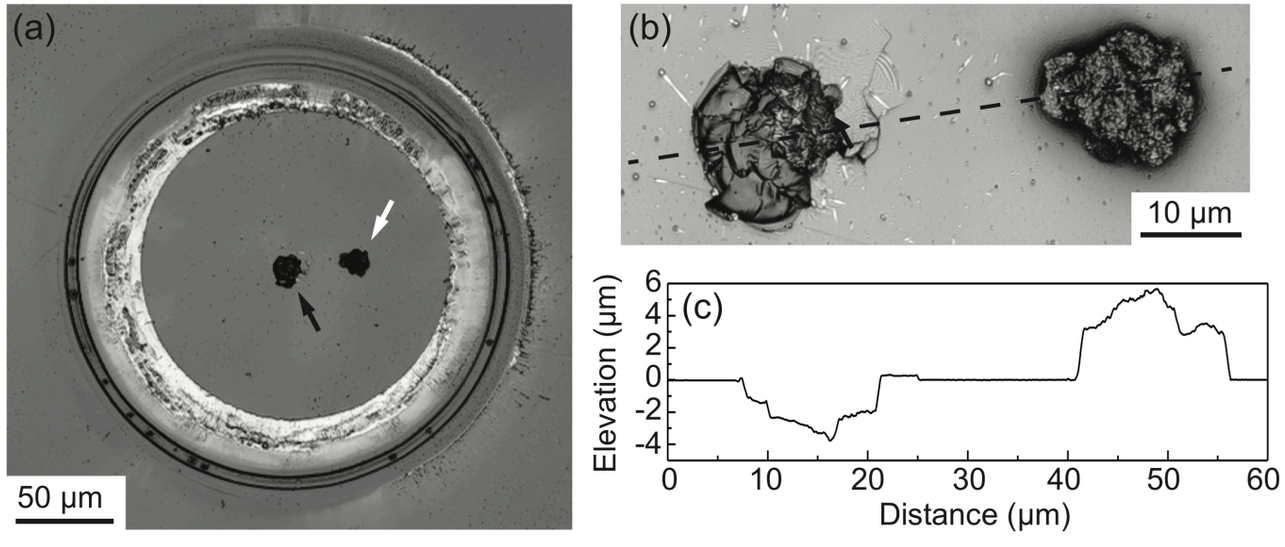
Threshold for glass fracture



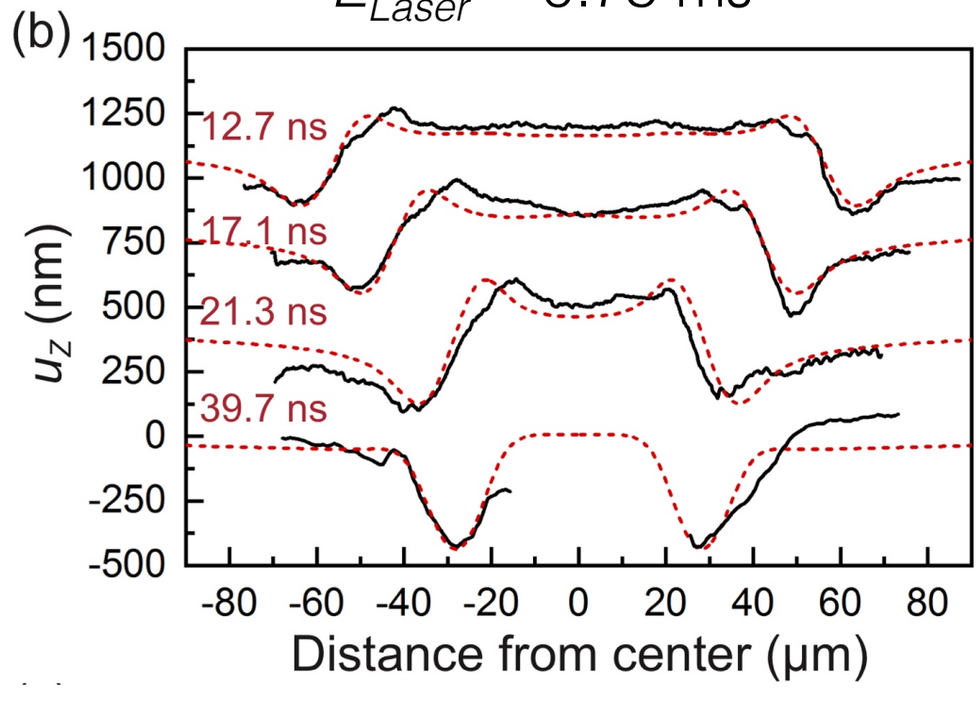
Experimental

Simulation (**linear**)

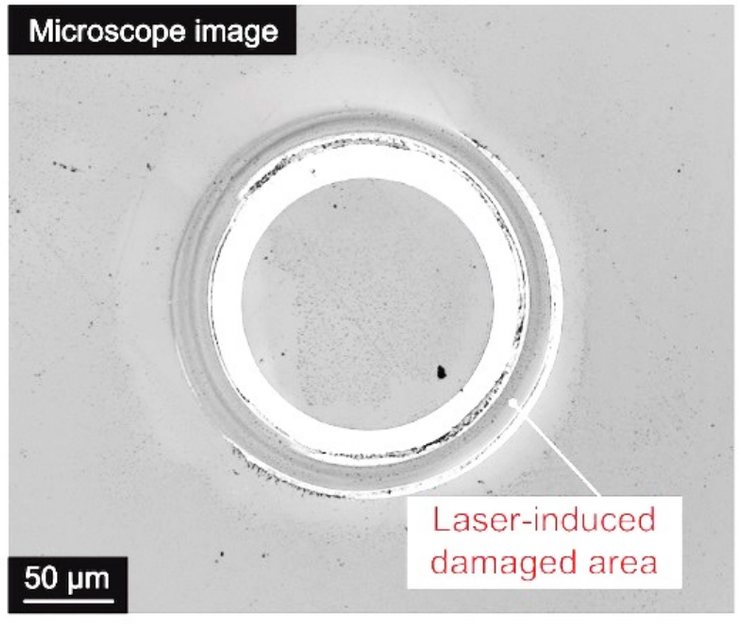
E_{Laser} = 1.00 mJ



E_{Laser} = 0.75 mJ



No visible damage



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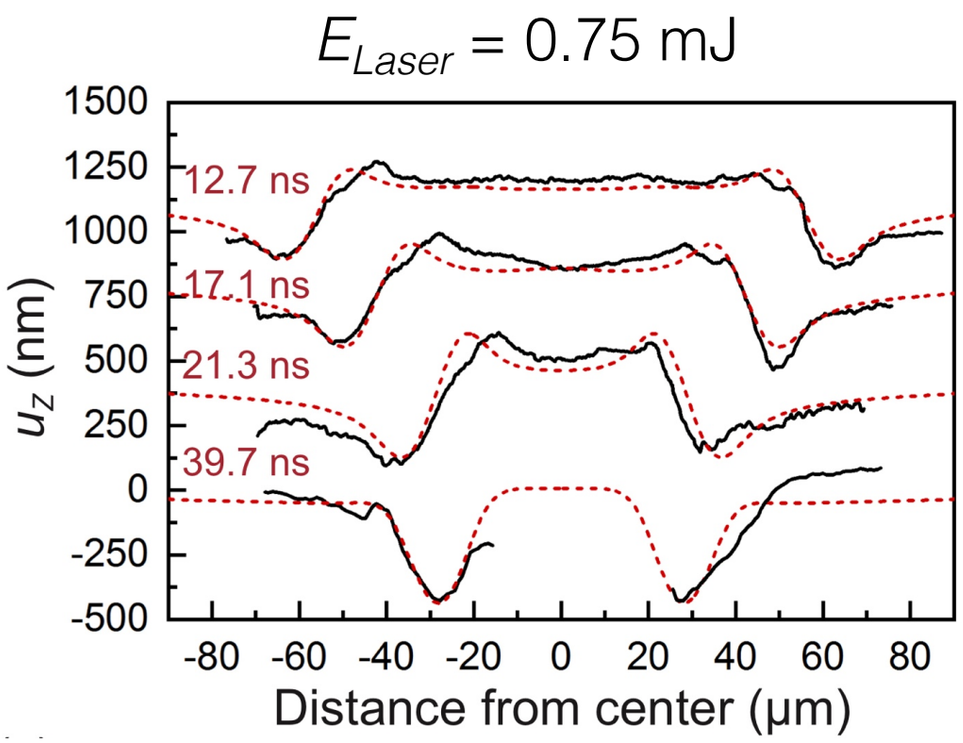
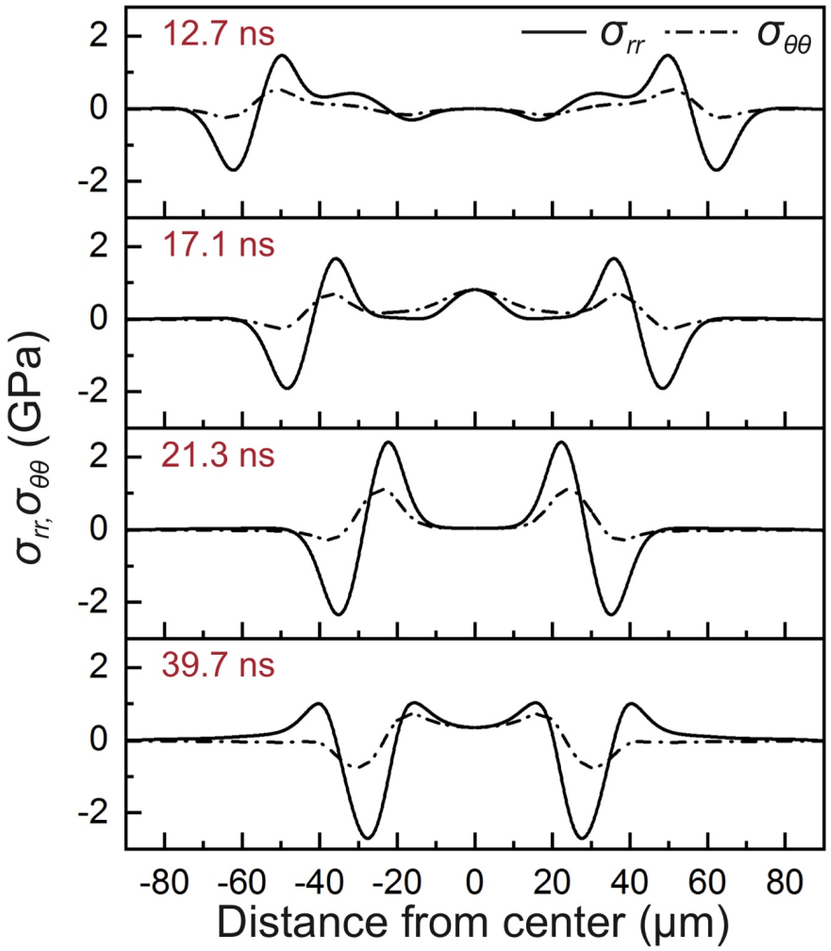
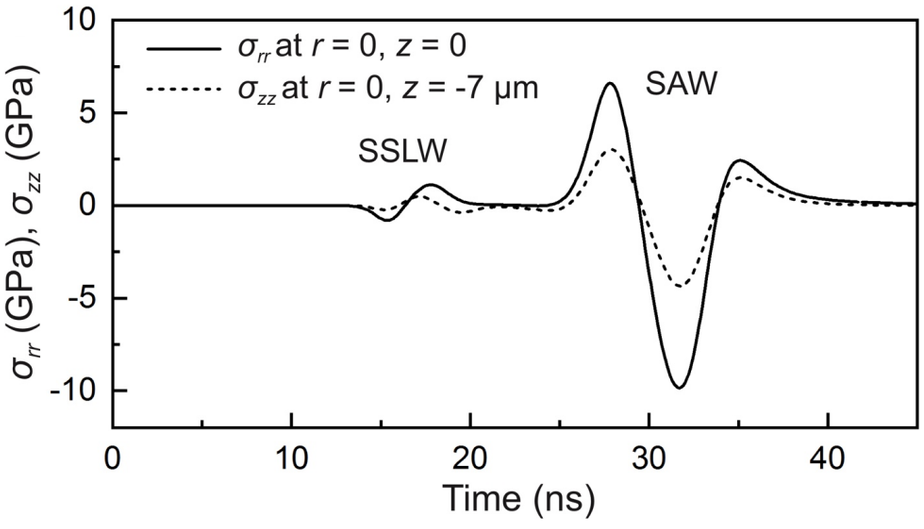




At the center of focus



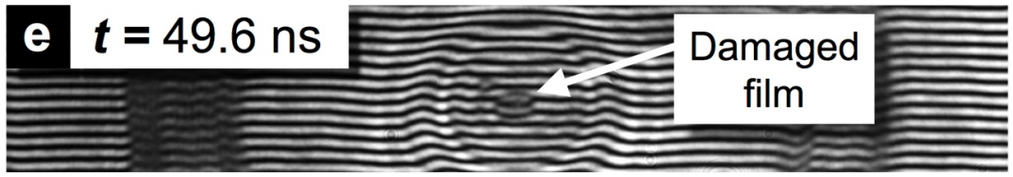
No pre-compression as in traditional spallation experiments

Glass withholds a tensile stress of 6.6 GPa at a strain rate ~ 10^8 s^{-1}

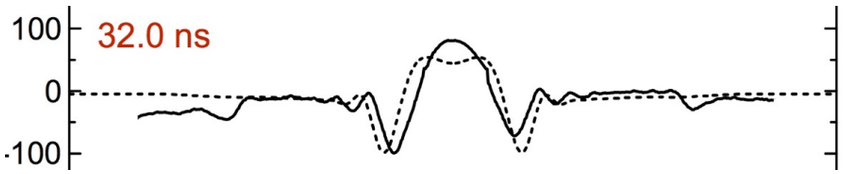
(no sign of permanent densification)

Conclusions

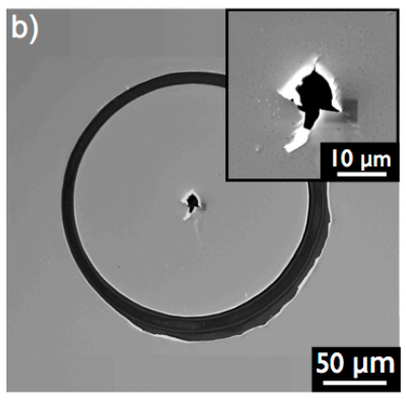
- Direct real-time visualization of focusing surface acoustic waves in glass is demonstrated in an all-optical experiment.

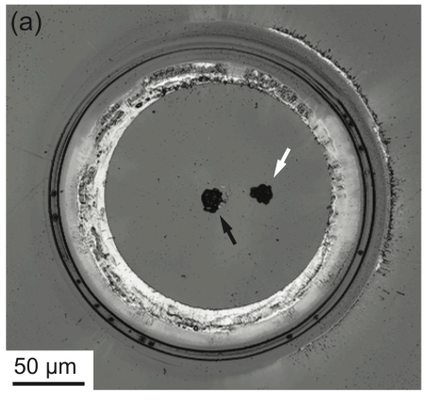


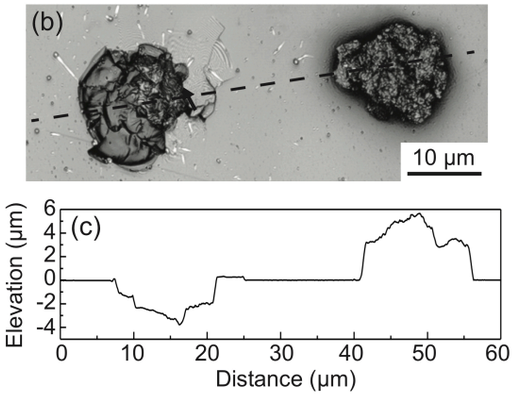
- The quantitative analysis of the full-field images provides direct information about the surface displacement and velocity.



- The focusing of the SAW leads to **ablation of the gold coating** and at higher energies to **damage in the glass substrate** at the focal point.







- The present method opens prospects for **ultra-high strain rate dynamic failure testing** of novel materials with limited available volumes and for refining fracture models.

Acknowledgments (2/2)

Thank you for your attention!

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Sample fabrication:
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Xin Zhang (Boston University).

Please, come to my posters!

- Advances in laser-induced microparticle impact experiments
- Bubble cavitation in water triggered by laser-driven focusing shock waves

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Funding was provided by the ISN through the U.S. Army Research Office, under Grant W911NF-13-D-0001 and through the Office of Naval Research DURIP Grant No. N00014-13-1-0676.