Coherent EUV light illuminates nanoscale phonon dynamics

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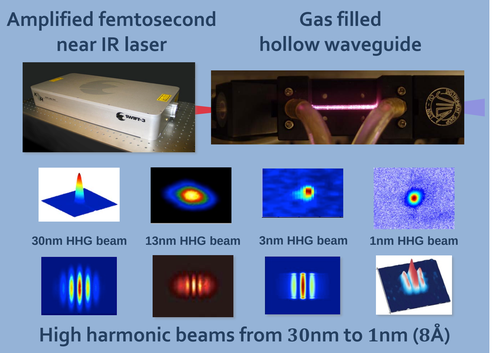
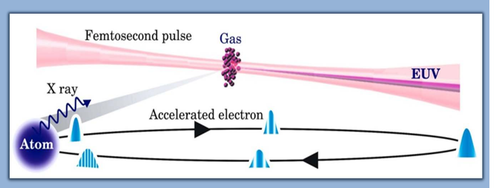
Tabletop laser-like X-rays

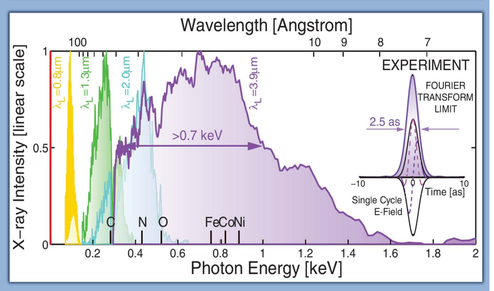


- Coherent extreme ultraviolet (EUV) to soft X-ray beams are generated by focusing a tabletop femtosecond laser into a gas-filled waveguide.
- Tabletop, full spatial coherence, 1-30nm, <10 fs pulse duration.

- Integrated 30 nm wavelength systems already commercially available.
- Control over polarization now possible

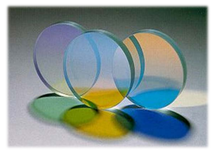
Opt. Lett. ***33****, 2128 (2008)*
PNAS ***106****, 10516 (2009)*
PRL ***105****, 173901 (2010)*
Nat. Photon. ***4****, 822 (2010)*
Science ***336****, 12878 (2012)*
Nat. Photon. ***9****, 99 (2015)*
Science **348**, 530 (2015)

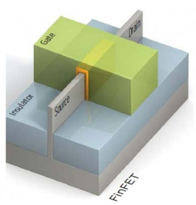




Motivation

Today's best nanofabrication for multiple technological applications has reached unprecedented size scales <u>where bulk models break down and reliable characterization tools do not yet exist</u>.


Thin film technology



FinFETs


Solar technology

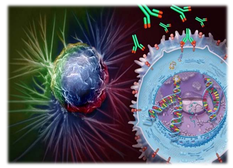

Nanomedicine

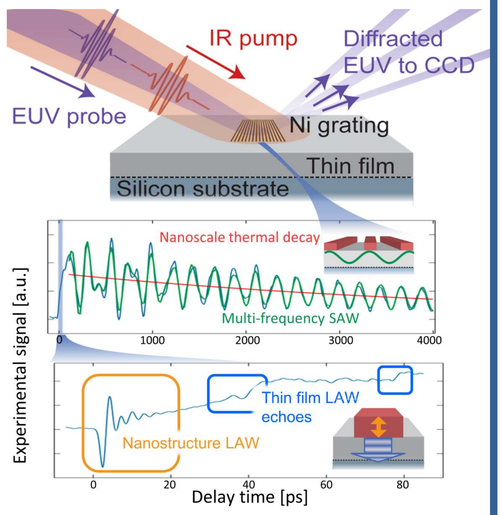
Table top sources of coherent EUV light open the door to probing nanoscale dynamics at their <u>intrinsic length- and time-scales</u>.

In dielectric and semiconductors, phonons are the main energy-carriers and dictate the thermal and elastic properties of the material. Directly probing phonon properties at the nanoscale is of great importance for both technological and fundamental science development.

The technique

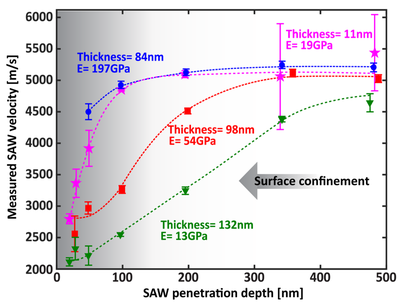
We focus an ultrafast infrared laser onto a nano-patterned ultrathin film on a substrate, causing thermal expansion of the nanostructures and launching surface acoustic waves (SAWs) and longitudinal acoustic waves (LAWs).

Coherent (EUV) <~10 fs short pulses at 30nm probe the surface deformation dynamics of SAWs, LAWs and the thermal strain, allowing the full characterization of the elastic tensor for isotropic thin films and simultaneously the quantification of deviations from diffusive thermal transport.



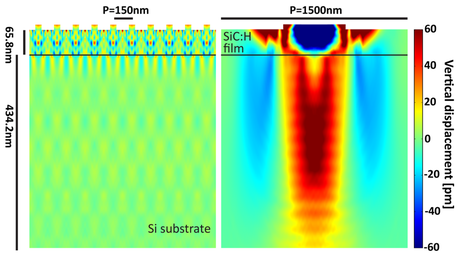
Hernandez-Charpak et al., SPIE Vol. ***9778*** *(2016)*
Hernandez-Charpak et al., Nano Lett. **Article ASAP** *(2017)*

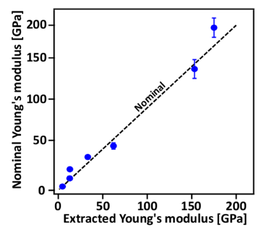
Ultrathin film metrology

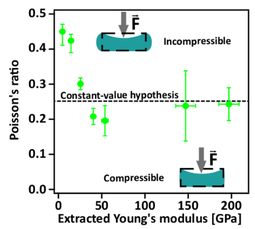


SAW penetration depth $\zeta \approx \lambda_{SAW}/\pi$: <u>detection of short-wavelength SAWs with EUV isolates film properties</u>.

- Changing grating period confines waves to either the substrate or thin film.

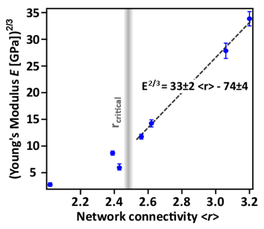


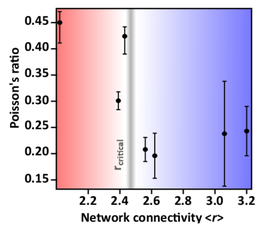




- <u>Simultaneous extraction of Young's modulus and Poisson's ratio</u> for 11-100 nm ultrathin isotropic films.
- Characterization of 11 nm thin film represents the <u>thinnest film fully characterized to date.</u>

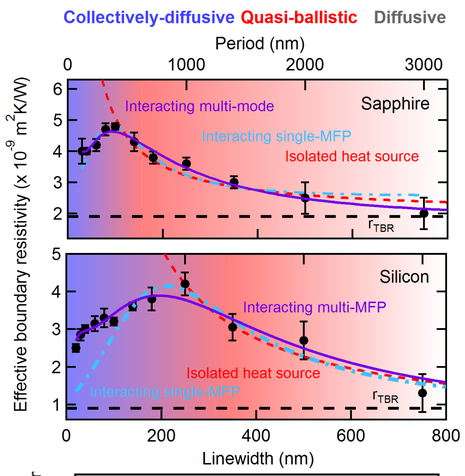
<u>New trend in Poisson's ratio</u> is observed in SIC:H films: Increasing hydrogenation decreases the network connectivity below critical value ~2.5. The material then transitions from compressible to incompressible.



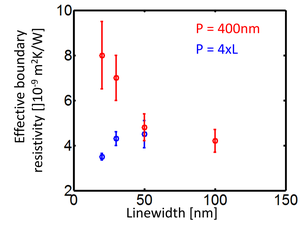


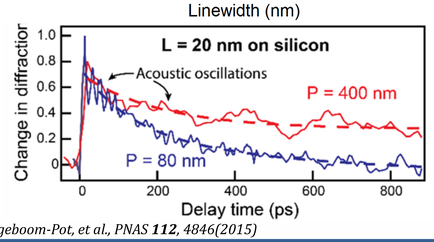
Hernandez-Charpak et al., Nano Lett. **Article ASAP** *(2017)*
DOI: 10.1021/acs.nanolett.6b04635

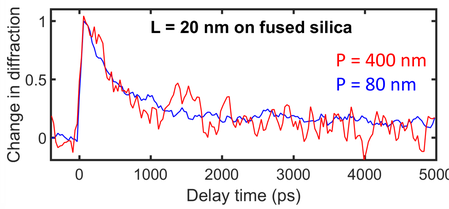
Nanoscale heat transfer



Probing heat dissipation away from heat sources as small as 20 nm in linewidth, we confirmed period-dependent non-diffusive transport, where <u>closely-spaced nanowires cool faster than widely-spaced ones.</u>







Hoogeboom-Pot, et al., PNAS ***112****, 4846(2015)*

Future directions

- Dynamic coherent diffractive imaging
- Coherent EUV transient grating excitation