Uncovering how the nano-world works using coherent extreme UV light

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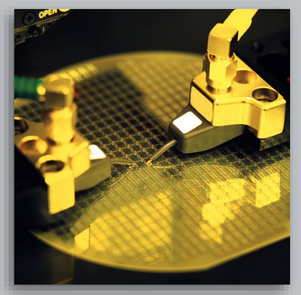
WHAT ARE WE MISSING?

The current landscape:



- Nanotechnology is ubiquitous with computing devices containing features at the nanometer scale and increasing use of nano-technology in medicine, clean energy and more
- Advanced electron microscopy techniques offer high spatial resolution over small areas and allow us to see the materials at atomically small size scales – but limited to static samples and with associated damage
- Synchrotrons and free electron laser facilities allow high resolution x-ray measurements, but are relatively inaccessible – precluding iterative designs, and most have poor time resolution
- New nanotechnologies are increasingly limited by our lack of understandings of the new physics that dominates nanoscale systems

To understand and optimize smart designs for next generation nanotechnologies, we need a new, broadly accessible, nanometrology tool set capable of observing the nano-world at its intrinsic length (nanometers) and time (femtosecond) scales relevant to function

ACKNOWLEDGEMENTS

This work was conducted at JILA using facilities provided by NSF Engineering Research Center in EUV Science and Technology with special thanks to my graduate advisors, Margaret Murnane and Henry Kapteyn, and collaborators Damiano Nardi and Jorge Hernandez-Charpak (JILA), Erik Anderson and Weilun Chao (LBNL), Justin Shaw (NIST), Marie Tripp and Sean King (Intel).

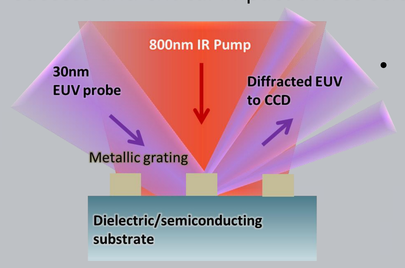
References: Hoogeboom-Pot et al. *PNAS* **112**, 4846 (2015)
Miao et al. *Science* **348**, 530 (2015)
Adams et al. *Laser Focus World* (May, 2015)

THE NEW TOOL WE NEED

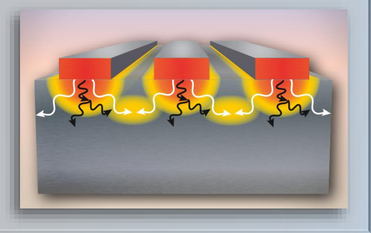
- Extreme nonlinear optics can convert high-intensity tabletop visible and infrared femtosecond laser pulses to much shorter wavelengths in a process known as high harmonic generation (HHG).
- This enables a tabletop, laser-like light source with extreme UV and soft x-ray wavelengths from 1-50nm and pulses shorter than 20fs, that are well matched to the dynamics found in the nano-world.
- New understanding of the full quantum nonlinear optical process allows as much control over the light source as standard lenses and polarizers have long offered for visible wavelengths or visible microscopes.

CASE STUDY: THERMAL TRANSPORT

Many recent results using HHG sources underscore their potential for success and critical impact across science and technology



- HHG extreme UV light source directly probed cooling dynamics of smallest heat sources ever studied (as small as 20nm in lateral size)
- Discovered completely unanticipated regime of nanoscale thermal transport where small heat sources can dissipate heat more quickly if spaced close together rather than far apart
- Suggests new strategies for thermal management in nano-devices and first method to characterize phonon properties controlling thermal transport



NEXT CHALLENGES

How to achieve shorter wavelengths and higher photon flux to improve measurement capabilities?

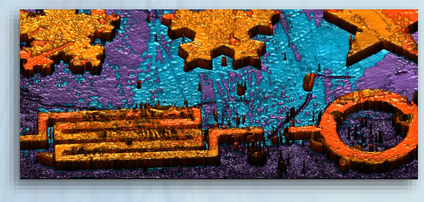
- Develop new mid-infrared lasers for high-intensity driving laser
- Discover alternative routes by learning more about HHG process in multiply ionized gases

How to improve accessibility and broaden applicability?

- Develop robust HHG system and incorporate into a set of metrology tools
- Understand and learn to interpret measurements of nano-systems that could not be studied previously

TRANSFORMATIVE APPLICATIONS

HHG light sources offer a critical new window into the dynamics of the nano-world, offering high resolution in both space and time in an accessible, small-scale source



Observe nano-systems at work → understand governing physics → harness unique properties and optimize designs → revolutionize applications, including:

- Miniaturized electronics for distributed sensing and monitoring
- More powerful and efficient supercomputers and data centers
- Nano-enhanced thermoelectric or photovoltaic devices
- Therapeutic nanoparticles in medical science