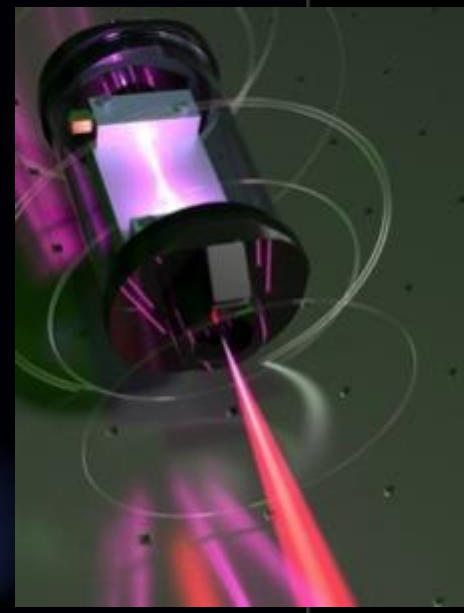


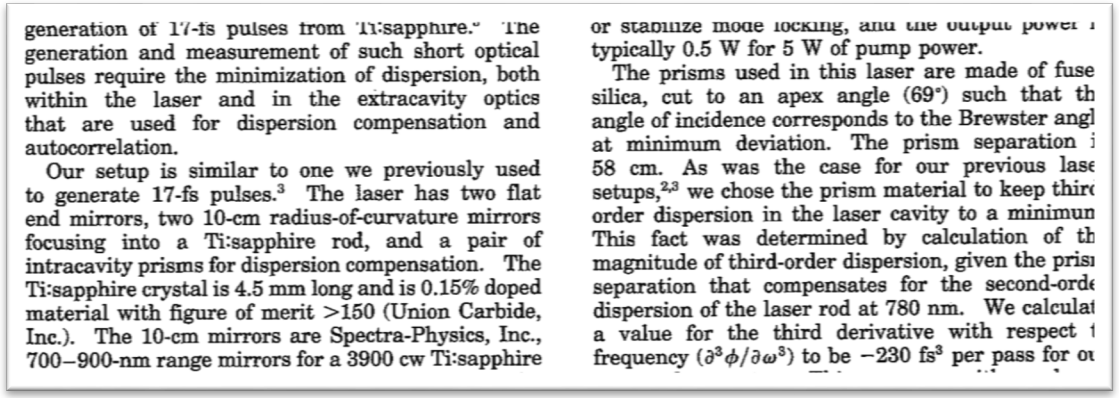
Commercializing quantum technologies: (the long road to) bringing coherent x-ray sources to commercial relevance

- Henry C. Kapteyn, CTO and co-founder, KMLabs Inc.

Who am I, and what is KMLabs?

- KMLabs is a University spin-off
  - Prof. Henry C. **K**apteyn
  - Prof. Margaret M. **M**urnane

- Started 1994– commercialized first ”few cycle” (10^{-14} sec= 10 fs) pulsed laser

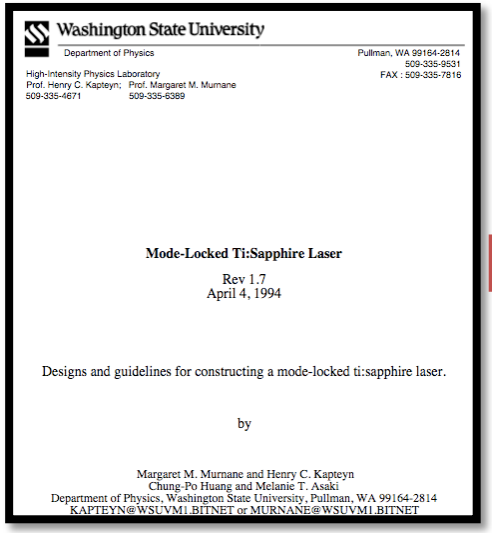


generation of 17-fs pulses from Ti:sapphire." The generation and measurement of such short optical pulses require the minimization of dispersion, both within the laser and in the extracavity optics that are used for dispersion compensation and autocorrelation.

Our setup is similar to one we previously used to generate 17-fs pulses.[3] The laser has two flat end mirrors, two 10-cm radius-of-curvature mirrors focusing into a Ti:sapphire rod, and a pair of intracavity prisms for dispersion compensation. The Ti:sapphire crystal is 4.5 mm long and is 0.15% doped material with figure of merit >150 (Union Carbide, Inc.). The 10-cm mirrors are Spectra-Physics, Inc., 700–900-nm range mirrors for a 3900 cw Ti:sapphire

or stabilize mode locking, and the output power typically 0.5 W for 5 W of pump power.

The prisms used in this laser are made of fuse silica, cut to an apex angle (69°) such that th angle of incidence corresponds to the Brewster angl at minimum deviation. The prism separation 58 cm. As was the case for our previous lase setups,[2,3] we chose the prism material to keep thir order dispersion in the laser cavity to a minimun This fact was determined by calculation of th magnitude of third-order dispersion, given the prisi separation that compensates for the second-orde dispersion of the laser rod at 780 nm. We calculat a value for the third derivative with respect t frequency ($\partial^3\phi/\partial\omega^3$) to be −230 fs^3 per pass for ot



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Mode-Locked Ti:Sapphire Laser

Rev 1.7
April 4, 1994

Designs and guidelines for constructing a mode-locked ti:sapphire laser.

by

Margaret M. Murnane and Henry C. Kapteyn
Chung-Po Huang and Melanie T. Asaki
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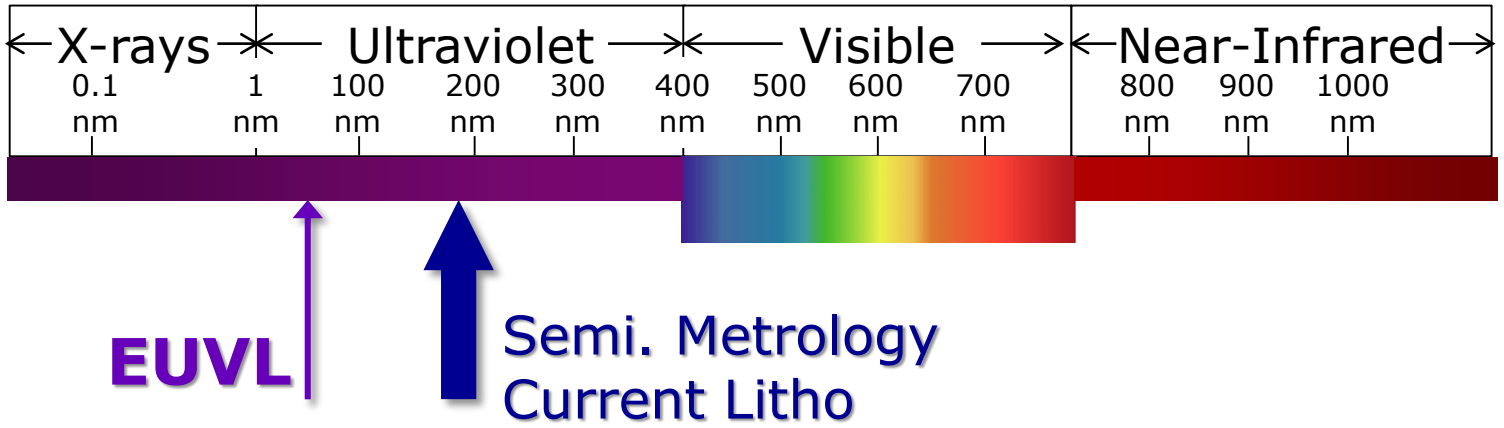
KMLabs Inc.

Company mission

- Commercial introduction of the first tabletop-scale **X-ray laser**– light source



Company mission

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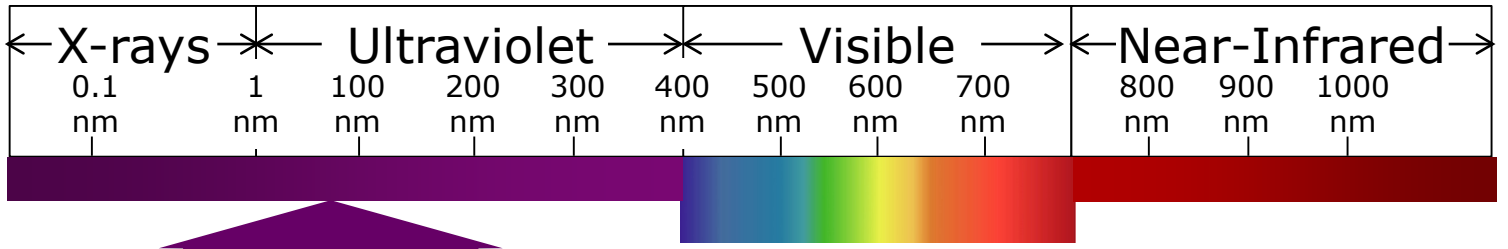
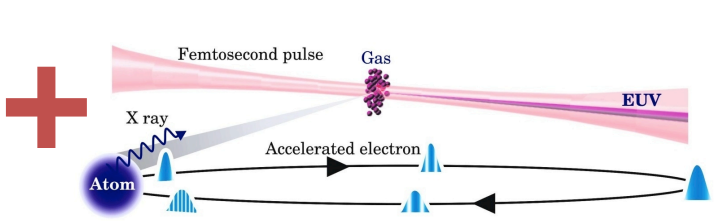
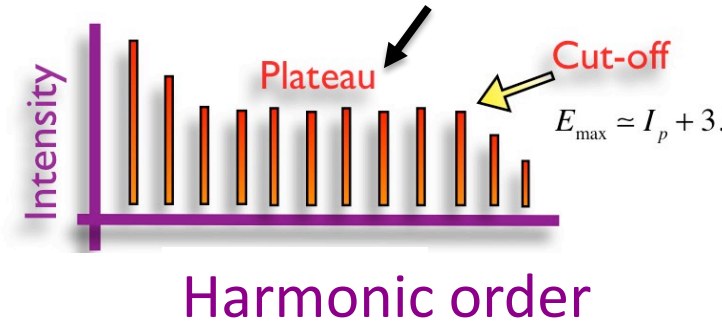


- The $XUUS_4^{TM}$: High power fs laser + High harmonic upconversion





Our experience with SBIR/STTR

- First SBIR grant ~2002, first Phase II 2010
- ~10 Phase II's, DoD, DoE, NSF
- Essential support for new "deep" tech development, but a balancing act
  - Respond to Solicitation in a way that advances company goals
  - Propose something truly exciting to reviewers → typically risky
  - Try to "piggyback" a useful product onto the research
- Products to-date:
  - Several variations of our KMLabs Wyvern laser system for specific tasks:
    - Wyvern-X: ILC accelerator photoinjector (DOE)
    - XUUS™ high harmonic source
    - Y-Fi™ ultrafast fiber laser and Y-Fi OPA™ for deep brain 3-photon imaging
    - **Direct Diode pumped ti:sapphire laser technology (DOE)**

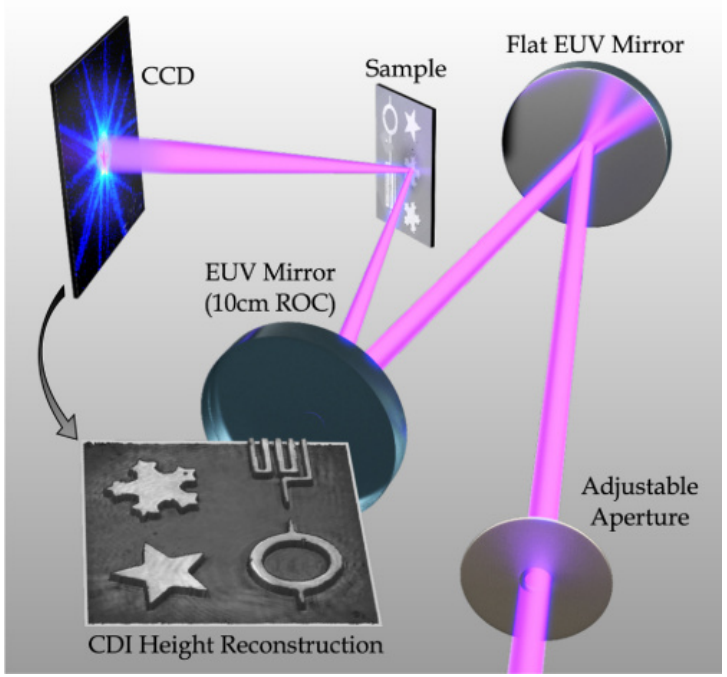
VC Funding

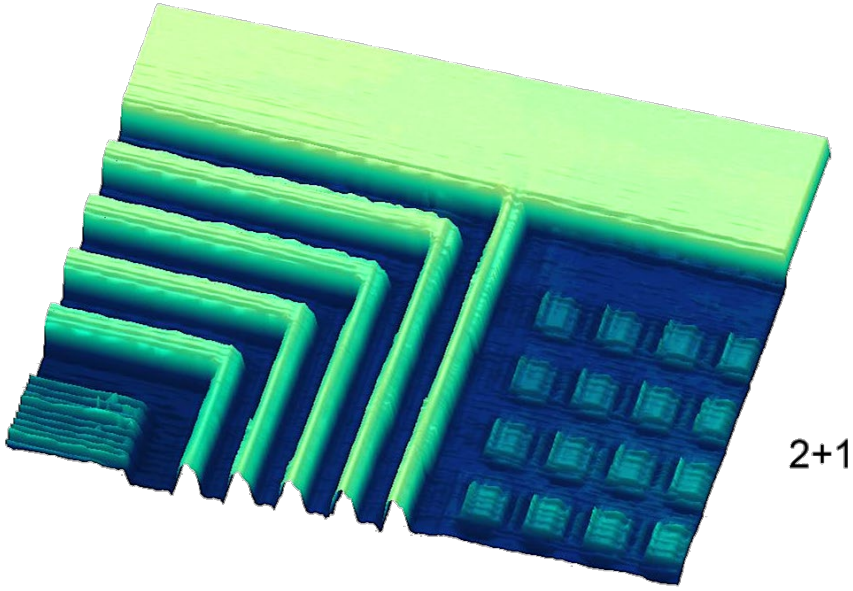
- Extremely-limited for “deeptech” difficult, expensive, transformational hardware
  - Strategic, Corporate VC funding
  - **Intel Capital, 2015 (2018)**
    - Intel capital summit: ~2 dozen funding events outlined→
      - KMLabs was the **ONLY** company whose goal was to produce products that Intel might use in mfr.
      - Others were primarily “users:” **software**, drones, computer accessories, 3D printing

- VC’s run in “packs”– Intel → Colorado Impact Fund → Kairos Ventures

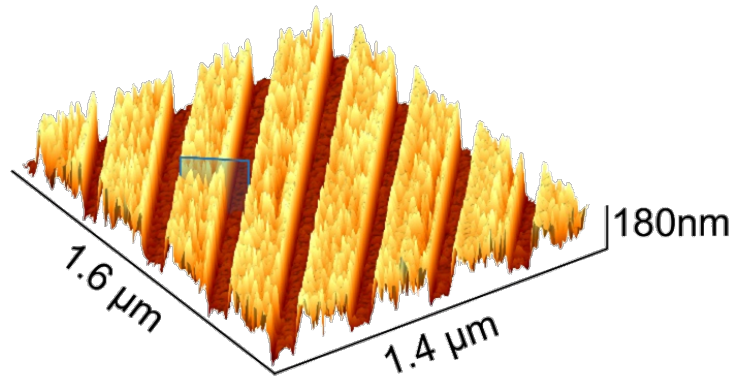
Why did we go the ”VC route” ?

- New short-wavelength imaging technology, “Coherent Diffractive imaging”
  - Application in nanotechnology, nanoelectronics.



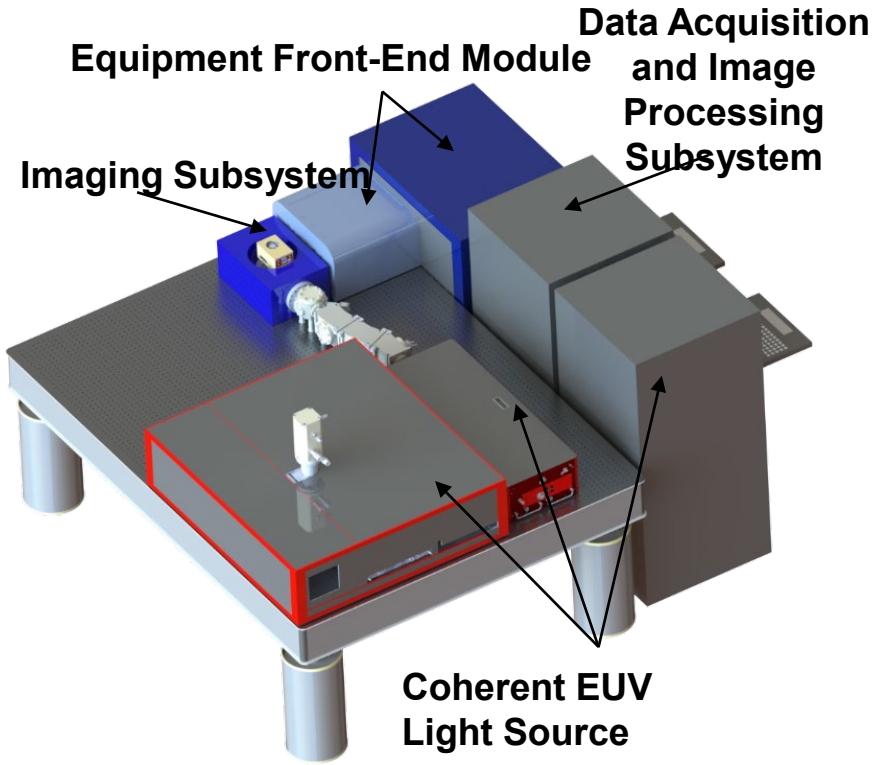


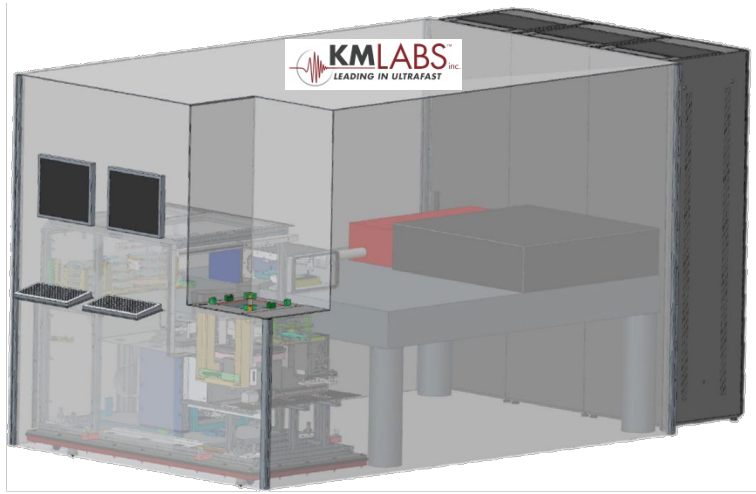
2+1D Phase Reconstruction



Why did we go the ”VC route” ?

- **TEAMS**™ – Tabletop EUV Actinic Microscope System
  - Typical “Tool” for SEMI is $5-20M
  - Development cost ~2-5 units
  - Zeiss “AIMS” $500M





Experience to-date

- Great group of investors
- Biggest benefit: profile, contacts
  - $$ is nice too, but not enough for success in the really tough topics
- Pitfalls:
  - Do you know who really understands the full picture?
- ”Deep tech” is hard
  - Established companies reluctant to adopt completely new technologies, even if superior
  - ”Valley of death” is very real, SBIR/STTR is not a solution. Neither is VC.
- Requirement– persistence, creativity, and flexibility
  - There is no proven formula

Strategy for US high-tech competitiveness

- Greatly increased international competition
  - At least a dozen companies in related areas in Europe
    - Funded through high $$ collaborative govt-industry projects, close ties with research institutes
      - “Frequency combs [femtosecond lasers] in space”
      - High-power fiber lasers
      - New ultrafast laser technologies
    - Mechanism regarded with suspicion in the US
  - Big $$, many companies in China

- In the US, we need more of the “aerospace model”
  - Routine access to space via commercial vehicles
  - “Valley of death” is widening in virtually all areas of deeptech
  - Need multiple mechanisms to harness innovations in small companies
  - Strategy to avoid missing the future high tech