Collaborations with Industry and Tech Transfer:

LIGO Laboratory's Experience

David Shoemaker

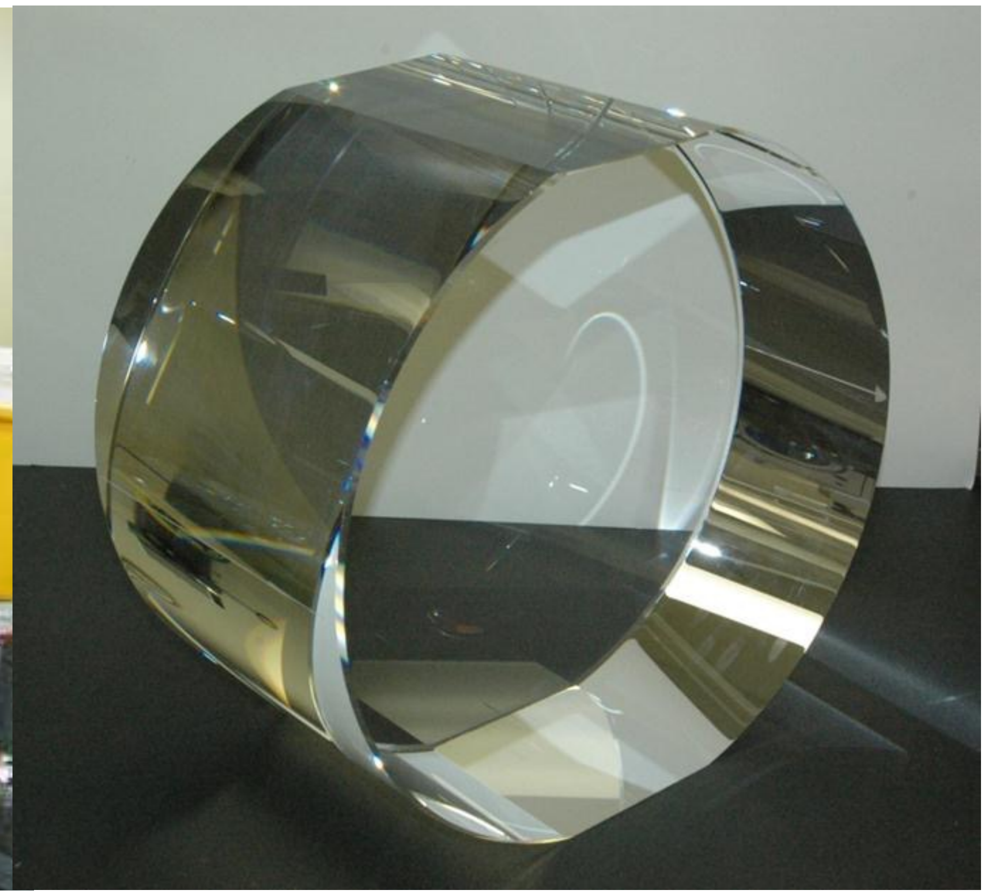
LIGO Laboratory

LIGO Technology

- The LIGO GW interferometers push the state-of-the-art in almost every type of technology that they use...
- ... and LIGO uses *many* different types of technologies.
  - Stabilized lasers
  - Squeezed light/quantum sensing
  - Precision mirrors and optical components
  - Sensors – seismometers, accelerometers, position sensors, tiltmeters
  - Precision metrology
  - Vibration isolation systems
  - Servo control systems
  - Vacuum systems and vacuum components
  - Massively parallel computing, low latency searches for MMA
  - Federated identity management for large collaborations
  - …
- Often, there are no 'off the shelf' solutions to meet our needs, so we partner with industry to develop components and systems that are needed to meet LIGO's requirements.

Example:
Advanced LIGO ‘Test Masses’

340 mm ⌀, 200 mm thick
40 Kg Fused Silica



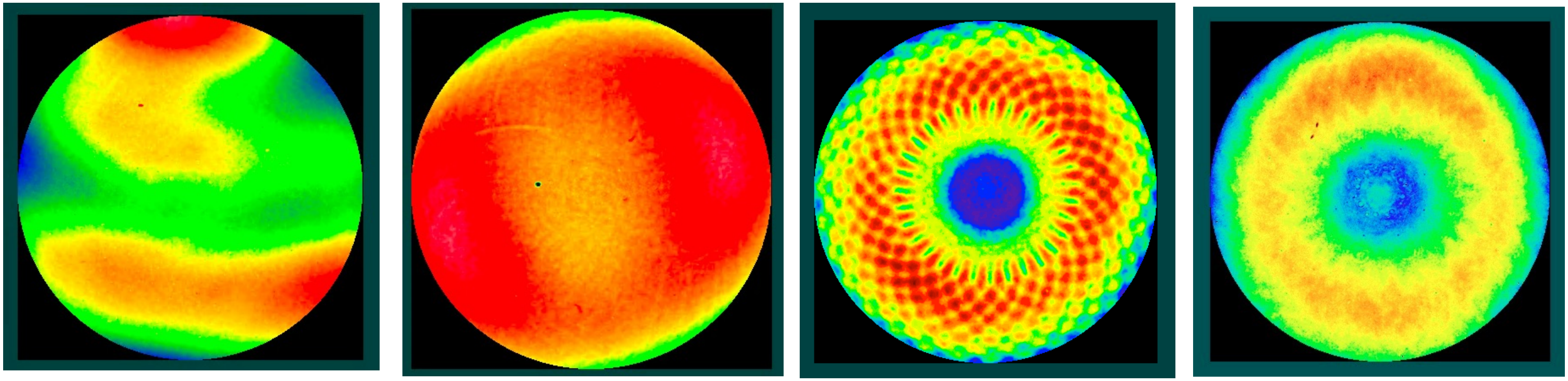
Case Study: Advanced LIGO Core Optics Coatings

- **Test masses coated by Laboratoire des Matériaux Avancés, Lyon, France**
- CNRS/INFN support, but also a commercial undertaking; LIGO awards competitive bids to LMA for optical dielectric coatings
- Unique capability at LMA to coat optics for GW detectors
- However: coatings initially did not meet requirements
- Over a 20-year period, significant interaction with LIGO with transfer of intellectual insights from LIGO to LMA to aid in their industrial processes

Coating challenges mitigated:

- Spirograph figure error
- Anti-Reflection coating performance
- Excess absorption
- Large radius figure error
- Transmission at secondary wavelength (532 nm)
- Point defects

Case Study: Advanced LIGO Core Optics Coatings



12 nm Peak-Valley
Feb 2011

11 nm PV

4 nm PV
"Spirograph"

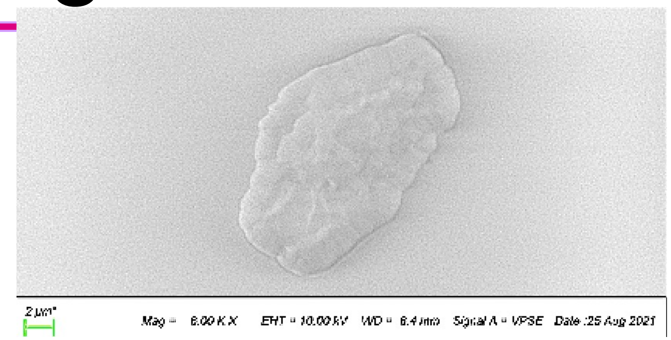
5 nm PV
Mar 2015

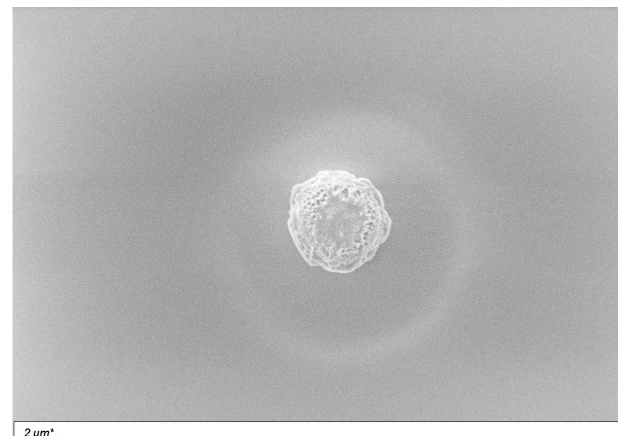
160 mm diameter

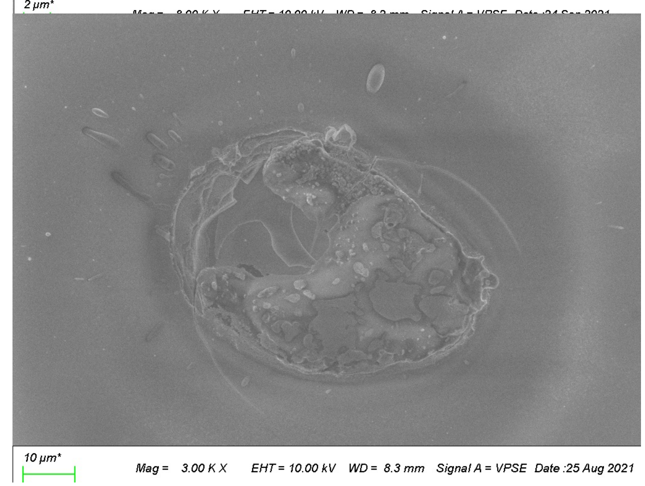
- Iterative improvement in the uniformity of the coatings
- LIGO provided characterization, interpretation, modeling, funding
- LMA engaged to improve the coating process
- LIGO's and Virgo's mirrors improved significantly

Case Study: Advanced LIGO Core Optics Coatings

- Point defects cause absorption of laser light, heat-induced distortion in the mirror surface
- Collaborative effort between LMA and LIGO to identify the nature of the defects
- Many absorbers are Aluminum, also seen Carbon, Titanium, Copper, Iron, Nickel
- Iterative process of discussions, coating chamber modifications, coatings, and (LIGO) characterization and analysis
- Result: most recent coatings have 0 or 1 defect
- LIGO and Virgo coatings now have this improved performance







advanced ligo

LIGO

Extending the Physics Reach of LIGO

Home | aLIGO Summary | aLIGO News | LIGO Technology Transfers | LSC | LIGO Lab | LIGO

LIGO Technology Development and Migration

Explore the menu of case study links (left) to view impacts of LIGO technology across the broader science and engineering community.

Technology Transfer Case Studies

LIGO Technology Migration

Photo-Thermal Interferometer

Advanced LIGO will be a world-leading observatory designed to detect gravitational waves from the most violent events in the Universe. For Advanced LIGO to succeed, technology has been developed by LIGO scientists and engineers to measure displacements less than 1/10,000 the diameter of an atomic nucleus. Innovations in areas as diverse as lasers, optics, metrology, vacuum technology, chemical bonding and software algorithm development have resulted directly from this pioneering work.

https://www.advancedligo.mit.edu/tech_overview.html

(or google ‘Advanced LIGO technology’)

LIGO Tech Transfer: Lasers and Optics

LIGO Technology Development and Migration

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Technology Transfer Case Studies

- LIGO Technology Migration
- Photo-Thermal Interferometer
- Adaptive Beam Shaping
- High Power Modulator
- Pound-Drever-Hall Locking
- Diode Pumped Laser
- Slab Laser
- Vacuum Cable Clamp
- Interferometric Displacement Sensor
- Oxide Bonding Techniques
- Fast Chirp Transform
- Blind Data Search Method
- Distributed Identity Management

Technology Type: Optical Components

High Power Electro-Optical Modulator

**** Institution:** ***University of Florida Gainsville***
**** Contact:** ***Volker Quetschke*** *volker.quetschke(at)utb.edu, 956.882.6723*
**** Funding Agencies:** ***National Science Foundation***
**** Technology Source:** ***LIGO Scientific Collaboration (LSC) members outside of LIGO Laboratory***
****** *Patent Thumbnail*

Co-inventor Volker Quetschke, Professor of Physics, University of Texas Brownsville

Laser metrology and many other scientific applications of high-power laser beams require the phase modulation of the laser field. Previous commercial phase modulators were incapable of handling laser powers in excess of a few watts without beam heating resulting in thermo optic distortion of the laser beam. Our newly developed electro-optical modulators (EOM) can handle up to 200W of continuous laser power with no beam degradation. These high-power EOMs attracted such strong interest that they were initially prototyped by the New Focus company (now a division of Newport Corporation), and inspired their new high-power KTP modulator standard product line. Our new design was also proven to reduce the spurious polarization and amplitude modulation of phase modulators by several orders of magnitude while eliminating the very strict alignment tolerances of earlier modulators. This enables new applications in

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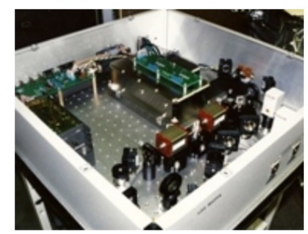
Technology Type: Lasers

Initial LIGO Diode-Pumped Solid State Laser

**** Institutions:** ***Lightwave Electronics and LIGO Laboratory***
**** Contact:** ***Tom Kane***
FASORtronics
PO Box 50370 LLC Albuquerque, NM 87181
www.fasortronics.com
**** Funding Agency:** ***National Science Foundation***
**** Technology Source:** ***Initial LIGO***



Lightwave Electronics (LWE) Corporation, of Mountain View CA, built the 10-Watt Diode Laser Pumped Solid State Lasers used in the Initial LIGO (iLIGO) Prestabilized Laser System (PSL). This project benefited LWE in three ways. First, it allowed LWE to make improvements to their laser system components product line. Second, it allowed LWE to hire a talented individual who has since become a top performer as both an engineer and a product marketer. Third, it created a small but profitable business, as LWE sold LIGO-design lasers to other customers.

Tech Transfer: Materials and Processes

LIGO Technology Development and Migration

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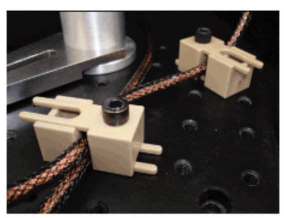
Technology Type: Ultra-High Vacuum Components and Techniques

Manufacturable Vacuum Cable Clamp

** Institution: *LIGO Laboratory*
** Contact: *Richard Abbott* *abbott_r(at)ligo.caltech.edu, 626.395.3449*
** Funding Agency: *National Science Foundation*
** Technology Source: *Initial LIGO*
** *Patent Thumbnail*

Clamp inventor Rich Abbott, Advanced LIGO Engineer

The most important inventions are often the simplest. Interferometric gravitational wave detectors are themselves complex scientific instruments. The in-vacuum optical systems (extremely high performance mirrors and beam-splitters) must be held free from all contamination (organic and particulate) while simultaneously being isolated from seismic noise. However, it is in addition necessary to apply electrical signals to control Isolatio System the opti pointing optical system. This requires the use of a lar (UHV) compatible electrical cables to route s outside the vacuum system through the vacu and the controlled optics. All of this must occur without compromising the ISI



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Technology Type: Materials Engineering

Oxide Bonding Techniques for Jointing Silicon Carbide

** Inventors: *Sheila Rowan, James Hough, Eoin John Eliffe*
** Institutions: *Glasgow University and Stanford University*
** Patent Application: *US2007/0221326)*
** Contact: *Sheila Rowan*
Sheila.Rowan(at)glasgow.ac.uk, 0141.330.4701
** Supporting Agencies: *NSF and PIPSS*
** Technology Source: *LIGO Scientific Collaboration (LSC) members outside of LIGO Laboratory*
** *Patent Thumbnail*

Close-up view of a machined mechanical attachment point bonded to an aLIGO mirror

Jointing techniques with high mechanical strength and stability are required for use in the fabrication of optical systems used in space-based applications such as telescope assemblies and optical benches. The original technique of hydroxy-catalysis, or "silicate" bonding was invented and patented at Stanford University by Gwo (1) for the purpose of jointing the fused silica pieces forming the star-tracking telescope assembly used in the Gravity Probe B space experiment. LIGO has used a variant of this technique to fabricate the quasi-monolithic fused silica

Tech Transfer: Cyberinfrastructure and Computing

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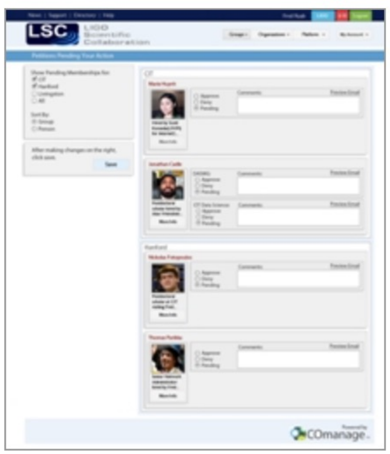
- *Slab Laser*
- *Vacuum Cable Clamp*
- *Interferometric Displacement Sensor*
- *Oxide Bonding Techniques*
- *Fast Chirp Transform*
- *Blind Data Search Method*
- *Distributed*

Technology Type: Distributed Computing

Federated Identity Management for Large Distributed Science Communities

**** Architect:** ***Scott Koranda***
**** Contact:** ***Scott Koranda***
scott.koranda@ligo.org
414.229.5056
**** Supporting Agency:** ***National Science Foundation***
**** Technology Source:** ***Advanced LIGO***

How many IDs and passwords do you need to remember? To buy an ebook, stream a movie, or download that latest app often means logging in with different IDs. Your bank, health insurance company, and physician offer the convenience of online services but each requires a separate ID, and smart online users create a unique ID/password combination for every site to protect themselves. The more you do online the more combinations there are to jot down on that sticky note pasted to your computer screen. Managing so



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- *Fast Chirp Transform*
- *Blind Data Search Method*
- *Distributed Identity Management*

Technology Type: Computation and Time-Series Data Analysis

Fast Chirp Transform

**** Institution:** ***California Institute of Technology***
**** Inventor/Contact:** ***Professor Thomas A. Prince*** *prince(at)caltech.edu*
Caltech Office of Technology Licensing 626.395.3822
**** Patent Number:** ***6,509,866***
**** Supporting Agency:** ***National Science Foundation***
**** Technology Source:** ***LIGO Scientific Collaboration (LSC) members outside of LIGO Laboratory***
**** *Patent Thumbnail***

Thomas A. Prince, Professor of Physics, Caltech

When two neutron stars combine into a single neutron star this process is described by three phases - the inspiral, merger and ringdown. In the initial inspiral stage of a binary neutron star coalescence the two stars spiral toward each other at a greater and greater angular velocity. During this inspiral phase the generated gravitational waves are expected to result in changes of gravitational strain with increasing amplitude and frequency resulting in a "up-chirp" signal. During the merger phase the prediction is much more difficult and currently rather uncertain but the signal properties are expected to be much more complex than a simple chirp. The final phase is called the ringdown phase in which the merged star undergoes damped body oscillations

Examples of LIGO Commercial Optical Technology Partners (an abridged list)

- Optics
  - AMSL
  - Research Electro-Optics
  - Advanced Thin Films
  - Laboratoire des Matériaux Avancés
  - CSIRO
  - Coastline Optics
  - Hereaus (Virgo)
- Lasers
  - Lightwave Electronics
  - Laser Zentrum Hannover
  - NeoLASE
- Electro-optic modulators and Faraday isolators
  - New Focus/Newport Corp
  - Moltech
  - Raicol
- Opto-mechanical components
  - Siskiyou
  - Lee's Mounts → Spindler-Hoyer

Lessons from LIGO in industrial collaborations and tech transfer

- LIGO's needs are very unique and challenging → defining and specifying requirements is very important
  - » The challenge often motivates companies to want to work with LIGO
- 'Throw over the fence' doesn't work → it's critically important, as much as possible, to work in a partnership with industry
  - » Careful management of intellectual property and proprietary processes is important
  - » High bandwidth communications between LIGO cognizant scientists/engineers and companies
- Contamination control and quality assurance/quality control comes into almost every aspect of the LIGO detector
  - » Initial LIGO had detector QA/QC, but needed much better QA/QC
- Money matters → developing state-of-the-art technology is risky and therefore expensive.
  - » Value engineering is critical to maintain budgets

And…Tech Transfer: Workforce

- Many students and postdocs in the LIGO environment
  - Some stay in the field
  - Some go to academic positions
- Many go to industry
  - High-tech training and the work culture in the Lab is excellent preparation
- Broad range of skills and destinations – Interferometry, mechanical engineering, programming; SpaceX, ASML, NASA, Google, etc.
- **This is perhaps the most important and enduring technology transfer value from LIGO to industry**

We are looking forward to Tech Transfer with Cosmic Explorer, the US next-generation GW Observatory