ISB: Optics Division

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The Optics division

- Core optics
- Laser sources
- Input and output optics
- Squeezed light sources
- Wavefront sensing and control
- Scattered light mitigation

High power / thermal effects

- Very low loss
- Very low loss
- Very low noise
- Low noise

Optical element, Fused Silica, room temperature
Optical element, Silicon, cryogenic

Laser beam 1550nm
Laser beam 1064nm
Squeezed light beam
ET-HF optics specifications/boundary conditions

- 3 MW circulating power @1064nm
- 12 cm beam radius (LG33/TEM00)
- Room temperature

ET-HF substrates

- Fused silica, 200 kg (5 × Adv. LIGO/Virgo)
  (2 × Virgo+)

ET-HF coatings

- With typical considerations, require 4 × reduction in coating loss compared to SiO$_2$ and TiO$_2$:Ta$_2$O$_5$ in Adv. LIGO/Virgo (for 12 cm beam)
- 0.5 ppm absorption target due to thermal compensation system (TCS).
- 10-20 ppm scattering limit per mirror (needs further review following 2G scatter challenges).
ET-LF optics specifications/boundary conditions
- 18 kW circulating power @1550nm
- 12 cm beam radius (TEM00)
- 10K (see cryogenics for status)

ET-LF substrates
- Silicon, 211 kg
  (sapphire may be considered - birefringence a challenge)

ET-LF coatings
- With typical considerations, require $3.8 \times$ reduction in coating loss compared to the loss of $\text{SiO}_2/\text{TiO}_2:\text{Ta}_2\text{O}_5$ at 10 K.
- < 5 ppm absorption (ideally sub-ppm to minimise heat load on test mass)
Example progress - optical coatings

Corner-sharing polyhedral fraction:
- $\text{Si:HfO}_2 < \text{Ta}_2\text{O}_5 < \text{SiO}_2$
- Cryo loss follows same trend
- Room temp loss opposite trend

Crucially important for developing improved amorphous oxides – different materials expected for HF and LF.

Example progress - optical coatings (contd.)

Molecular Dynamics Mechanical Spectroscopy (Puosi VIR-0854A-19 LIGO-G1901646
- apply stress and compute strain
- phase shift $\propto$ mech. Loss
Good agreement with $\text{Ta}_2\text{O}_5$ loss
Example progress - optical coatings (contd.)

Other materials/technologies *e.g.* $\text{SiN}_x$

**AlGaAs** crystalline (requires transfer/scaled-up)

$\text{AlGaP}$ crystalline? Lattice-matched c-Si / early dev.

$\text{a-Si}$ amorphous? Absorption still challenge so sole use

$\text{GaN}$? Promising but undeveloped

$\text{TiO}_2:\text{GeO}_2$? Proposed A+/V+ soln (ET ✓ ?)

$\text{TeO}_2:\text{GeO}_2$? Atomic structure could be highly promising / control of structure/stoch. challenging

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**Figures**

- Coating loss angle vs. frequency for various materials.
- Diagram of a DBR structure with lattice-matched layers.
- Graph showing properties of different materials.

**References**

Laser sources

Requirements:
- ET-HF: High power (700W)
- Beam quality (TEM00)
- Low beam pointing noise
- Low intensity noise (~AdV+/10)
- Low phase noise
- High reliability
- ET-LF: low power (5W) but very low noise at LF – beam jitter, scattered light

Present technology:
- Fiber amplifier: AdV+ ~100W
  ⇒ Improve and combine coherently several sources?
- Pre-mode cleaner (mode filtering + beam pointing)
Input optics

Interface between laser source and ITF, provides:
- Pure TEM00 beam
- Very stable in frequency, power and pointing
- Phase modulation for longitudinal and angular controls

Components:
- EOMs
- Faraday isolators (high vacuum compatible)
  - Technology to be developed at ET-LF wavelength
- Mode cleaner cavities (beam filtering & frequency stabilisation)
- Mode matching telescopes (tunable)
Readout of the dark fringe beam and auxiliary beams for controls

- Mode filtering of the dark fringe
- Squeezing injection
- Photodetection of the beams

Components:

- Mode matching telescopes (tunable)
- Faraday isolator (low optical loss)
- Output mode cleaners (low optical loss)  
  - Presently 2 types of cavities: monolithic / tombstone
- Photodiodes (high QE, very low noise electronics)

Thermal effects and cavity noise
Squeezed light

Provides the squeezed light at the required angle
• Squeezed light source
• Faraday isolators (high isolation)
• Filter cavities (low phase noise)
• Mode matching

All components with very low optical loss

Existing technology at 1064nm
- Frequency dependant squeezing being prepared for AdV+ and A+
- Losses to be reduced to reach 9 dB

To be developed at 1550nm
Wavefront sensing and control

Reduction of optical losses due to beam mismatch

• Sense the core optics deformation (global thermal effects, point absorbers)
• Correct those deformations
• Ease ITF controls during transients

Components:
- Wavefront sensors
- Ring heaters, Co2 lasers (low noise)
- Mode matching optics
Prevent parasitic noise from scattered light into ITF beam:
- Modeling of scattered light coupling to ITF beam
- Reduction of parasitic light scattered by all optical elements

Components:
- Simulation software
- Guidelines for the design of optical benches
- Monitoring systems (ex: instrumented baffle in AdV+)
- Reduction of scattered light (high quality baffles and beam dumps, ...)
- Reduction of mechanical motion of scattering elements (high quality mechanical mounts)
Many challenges ahead of us ...

• **Improve the present technology at 1064nm for ET-HF**
  – High power
  – Reduce and control thermal effects
  – Minimise optical and mechanical losses (core substrates, coatings, all optics)
  – Lower the noises (scattered light, photodetectors,...)

• **Develop the technology at 1550nm for ET-LF**
  – Squeezed light, Faraday isolators,...
  – Low noise at low frequency (scattered light, beam jitter,...)
  – Minimise optical and mechanical losses (core substrates, coatings, all optics)

... do not hesitate to join the effort!

Related R&D talks in tomorrow’s session:
- Higher-order Hermite-Gauss modes for gravitational waves detection by Walid Chaibi
- R&D on coatings by Jessica Steinleichner