Summary of Thermal Noise and Coatings Workshop

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On behalf of workshop participants

G1601218

Outline

- Introduction
- Highlights
  - Amorphous coatings
    - Ideal glasses
    - Structure characterization and modeling
    - Higher refractive index coatings
  - Crystalline coatings
- What's possible
  - Now, 1-3 and 3-5+ years time
- What's next
  - Science and Engineering
  - Organization

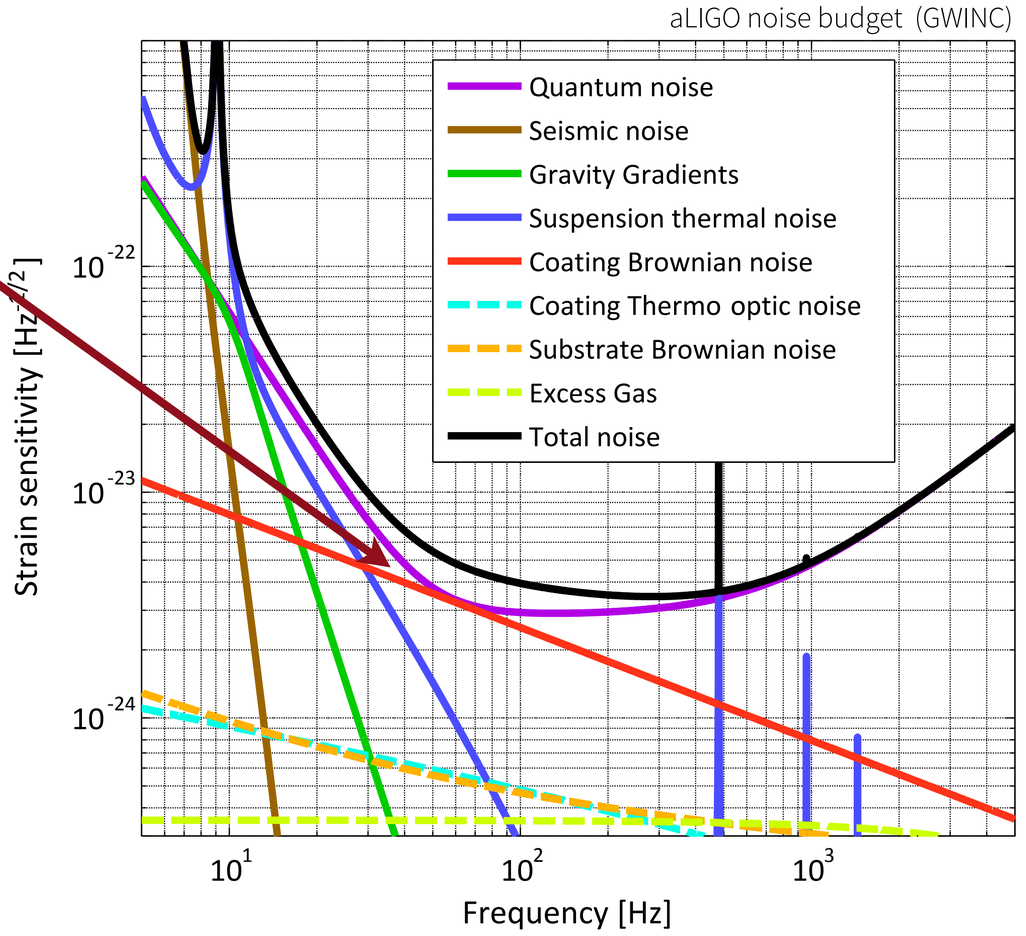
Introduction

- Reducing coating thermal noise is key challenge for future detectors:

$$S_x(f,T) \approx \frac{2k_B T}{\pi^2 f}\frac{d}{w^2 Y}\phi\left(\frac{Y'}{Y}+\frac{Y}{Y'}\right)$$

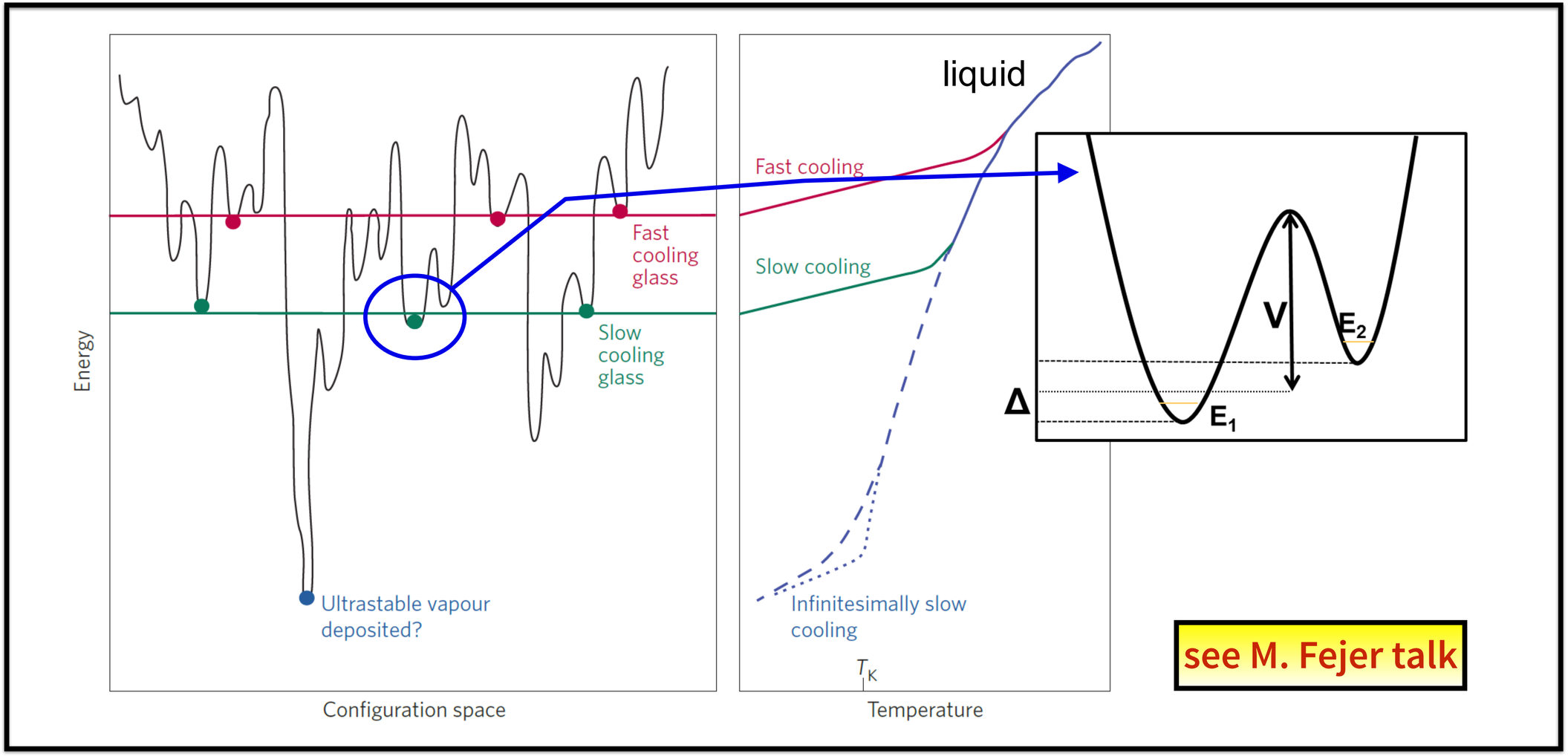
temperature, coating thickness, laser beam radius, coating mechanical loss

- Number to beat:
  - Mechanical loss Ti:Ta_2O_5 = 2 x 10^{-4}
- Plausible goals:
  - A+ LIGO: room temperature < 1x10-4 2X better
  - LIGO Voyager (cryogenic): 120 K < 2x10-5 10X better
- Need to maintain optical properties over 34 cm + diameter:
  - at 1.06 m for A+-LIGO
  - at ~1.5 - 2 um for cryo LIGO Voyager
  - optical absorption ~0.5 ppm
  - micro-roughness scatter ~1 ppm



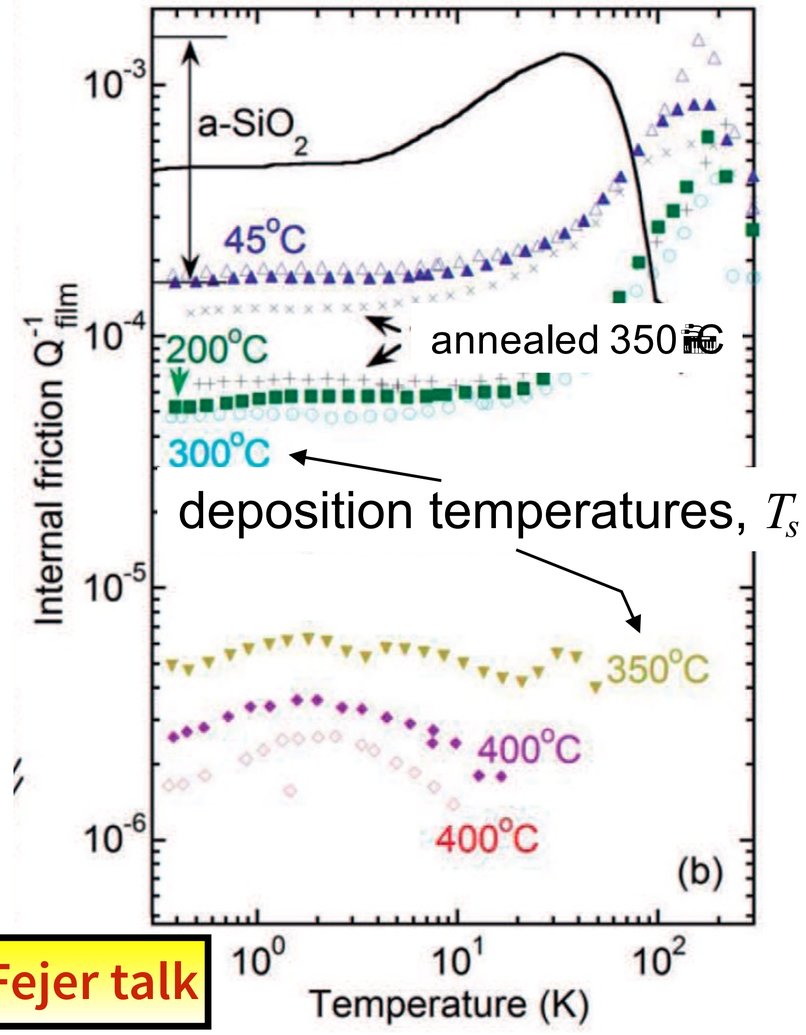
Highlights: Ideal Glasses

- Ideal glass: lowest energy state with minimal Two Level Systems (TLS)



Highlights: a-Si

credit: F. Hellman

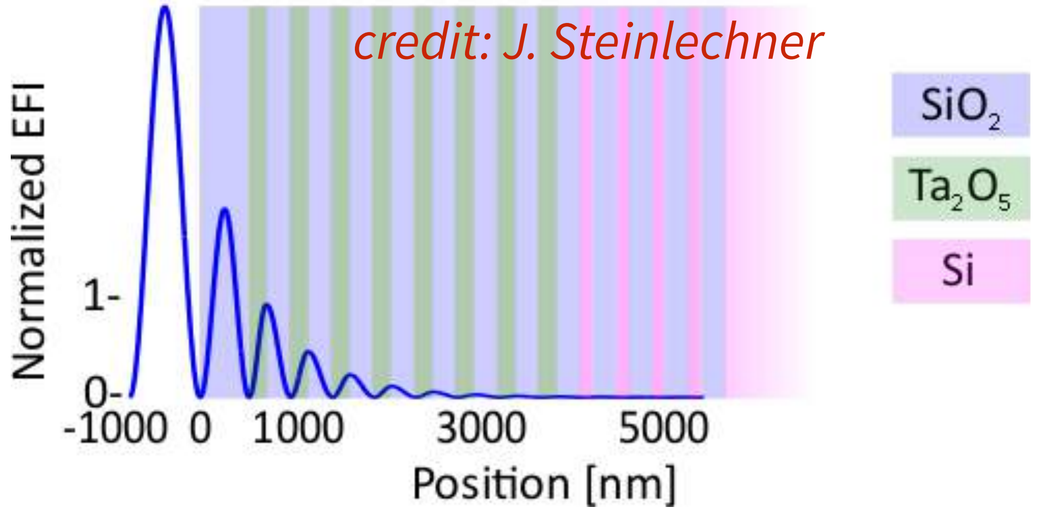


see M. Fejer talk

aSi attractive high-index material choice for aLIGO+ and beyond

- Optical absorption of 20ppm for HR stack feasible
  (reason due to unique dep parameters – low dep rate + high ion energy)
- Mechanical loss ~ $5x10^{-5}$ (room temp deposition + heat treatment at 400C)

credit: J. Steinlechner



Room temperature:
ITM: - 0%
ETM: - 28%
~~total: -18%~~ 21.5%

see S. Reid talk

Almost no improvement by reducing mechanical loss further (limited by silica loss and ITM thermal noise)

~~$1.2e-4$~~ $5x10^{-5}$

*Loss for aSi: 1.2e-4 measured on UWS aSi coatings at room temperature

Highlights: Increase refractive index

- Increase refractive index, reduce the number of HR stacks

	TiO2Ta2O5	new high-index layer
$\Phi_{\sim 2.5\ kHz}$	$(3.20 \pm 0.04) \cdot 10^{-4}$	$(3.41 \pm 0.13) \cdot 10^{-4}$
$\Phi_{\sim 14\ kHz}$	$3.9 \cdot 10^{-4}$	$(3.8 \pm 0.5) \cdot 10^{-4}$
$n_{1064\ nm}$	2.050 ± 0.005	2.095

similar loss
higher index

thinner layers

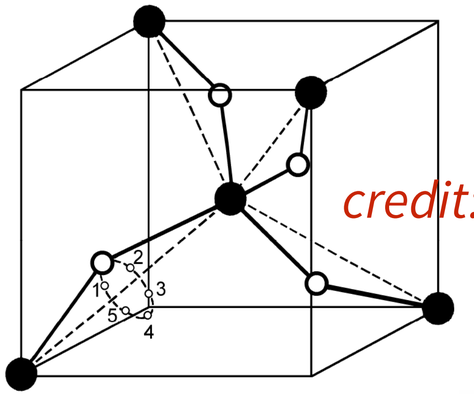
6% thinner ETM stack
[-1 doublet]

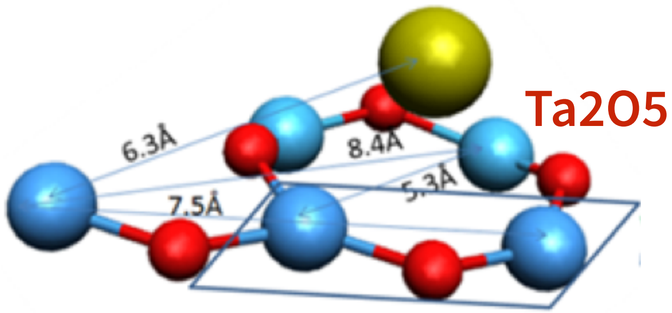
lower stack loss
expected

see M. Granata talk

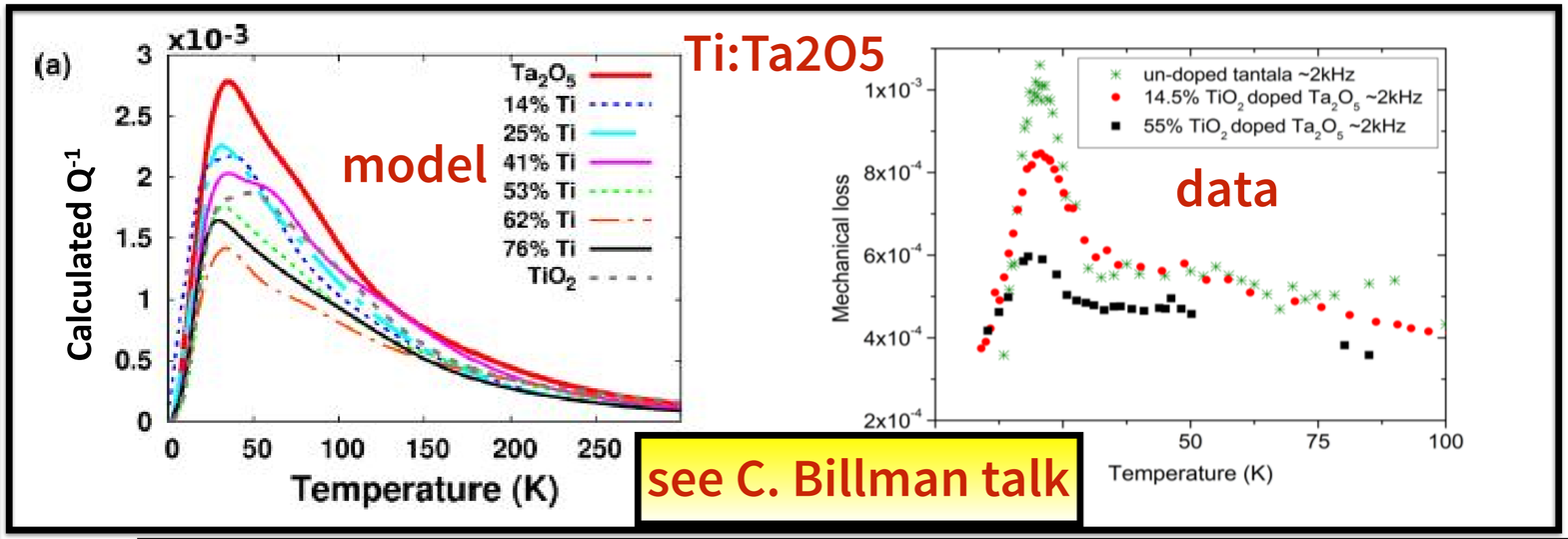
Highlights: Structure and modeling

- Structure characterization and modeling converging on mechanical loss understanding



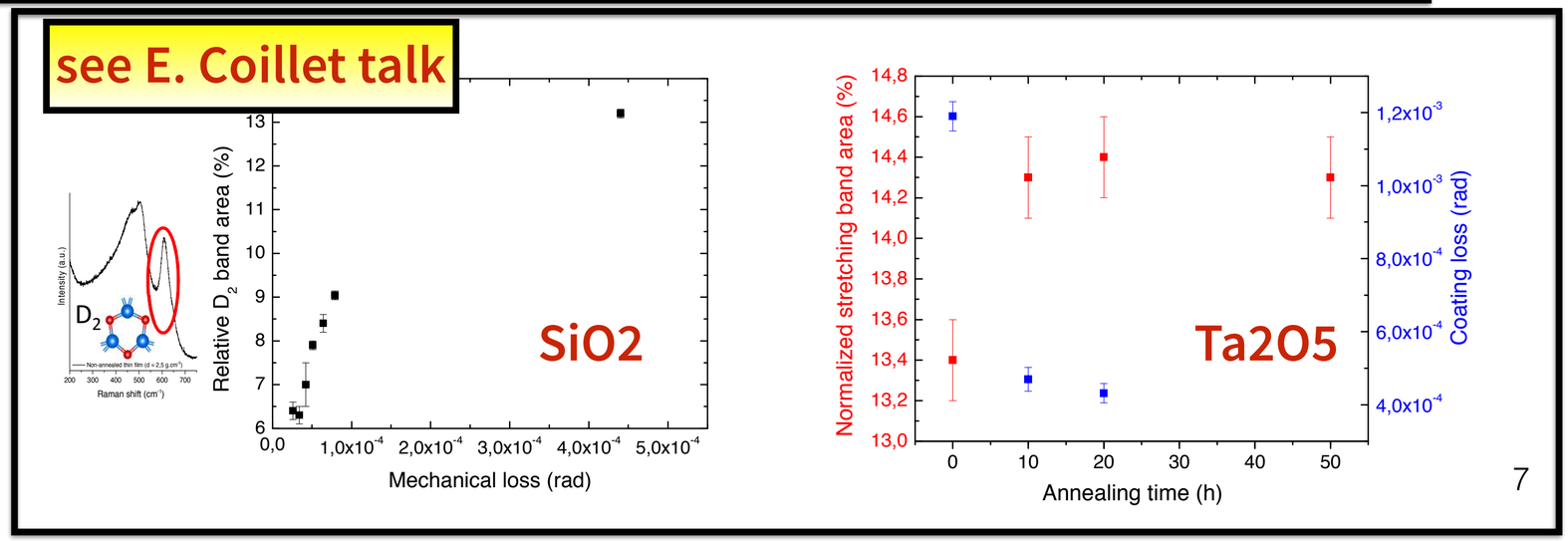


see R. Bassiri talk

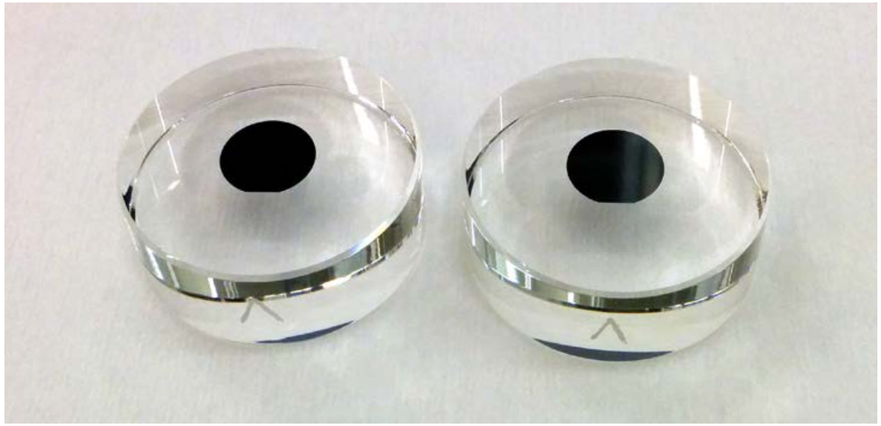


see C. Billman talk

see E. Coillet talk



Highlights: Crystalline coatings



free-standing epitaxial AlGaAs

reflectivity >0.9999 (ppm losses)

loss angle $<2 \times 10^{-5}$ to $<5 \times 10^{-6}$

see G. Cole talk

Crystalline coatings are a viable option for large-area low-noise optics, though a lot of work remains to be done

- Properties must be studied against LIGO specifications
  - wavefront error of large-area coatings must be studied
  - the same samples can be used to verify optical (and potentially mechanical) performance of our coatings
- Further scaling investigations must be initiated
  - a staged approach involving increasingly larger optics should be started as soon as possible (150 or 200 mm diameter parts?)
- GaAs substrate development will have to start soon
  - crystal growth manufacturers need ~2-3 year head-start
  - can be co-funded via semiconductor microelectronics industry

What's possible

- What we know has lower thermal noise now:
  - Change in e.g. titania doping to increase refractive index:
    - Possible some other dopant to same affect
    - LMA have coating with ~ 6% TN reduction
  - Multi-material a-Si for ETMs:
    - a-Si buried in the lower layers of the HR stack
    - @1064 ~ 20% TN reduction

What's possible

- What's possible in 1 – 3 years:
  - Elevated temperature deposition
    - Makes lower loss on a-Si coatings
    - Postulate lower loss in traditional oxides
  - Higher temperature annealing before crystallization reduces loss
    - Nano-layer Titania-Tantala coating
    - Zr:Ta2O5 (does not crystallize at 700C – loss under investigation), other dopants/oxides?

- What's possible in 3 - 5+ years:
  - AlGaAs
    - Currently low loss, low absorption, low scatter loss in small cavity
    - Need to scale to large area – study absorption, scatter, uniformity, figure error
  - AlGaP – proven low loss – other parameters need further study

What's next - Science/ Engineering

- Key deposition parameters to study:
  - Elevated temperature
  - Low deposition rate
  - Ion assist
- aSi absorption:
  - Reduction of dangling bonds
  - Hydrogen dope samples - known to reduce absorption
- Higher index and annealing temperature:
  - Add Ti for higher index
  - Absorption measurements needed for higher Ti concentrations

What's next - Science/ Engineering

- Structure characterization:
  - Theory vs. Experiment
    - Closer interaction going forward
  - Theory of deposition

- Comparison of Loss techniques:
  - Cantilevers vs. discs
  - Standard sample set for all measurements

see M. Lorenzini talk

- Scatter loss:
  - Specifications for scatter?
  - Standard technique?

What's next - Science/ Engineering

- After the solution is found:
  - Requires 2-3 years of engineering development for amorphous coatings

- Other coating development considerations:
  - Anti reflective coatings with R < 20 ppm
  - Coatings with reduced point defects
  - Enhanced Faraday isolators
  - Conductive coatings
  - 50/50 beam splitters
  - Enhanced coating thickness uniformity

What's next - Organizational

- Strengthen international collaboration

- Interaction with NSF:
  - Plan for near term research proposal
  - Draft prepared in advance of July DAWN meeting

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We're making great progress!

All talks available GWADW website: tinyurl.com/GWADW16

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