Crystalline coatings

S. Reid, with contributions from Cole/Penn/Harry/Fejer and Glasgow

GWADW Elba 2019

Technologies

- AlGaAs

- Mechanical loss all Ts ✓?
- Developed technology ✓
- Optical performance ✓

- Grown on GaAs wafers ✗
- Requires transfer ✗?

- AlGaP

- Mechanical loss 20-120K ✓
- Lattice matched to silicon ✓

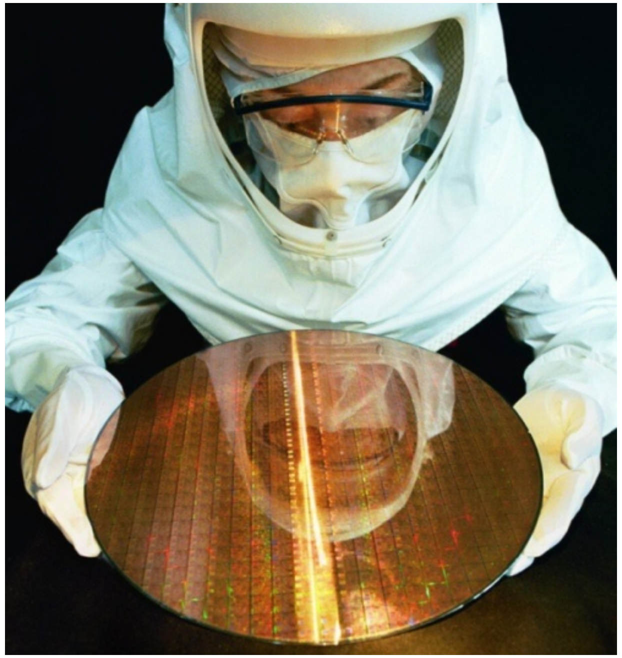
- Not well-developed ✗
- Optical properties ✗
- Growing on 200kg scale optics ✗?

Further outstanding questions… at end for discussion

AlGaAs

- Garret Cole (CMS) kindly created some slides regarding scaling AlGaAs.

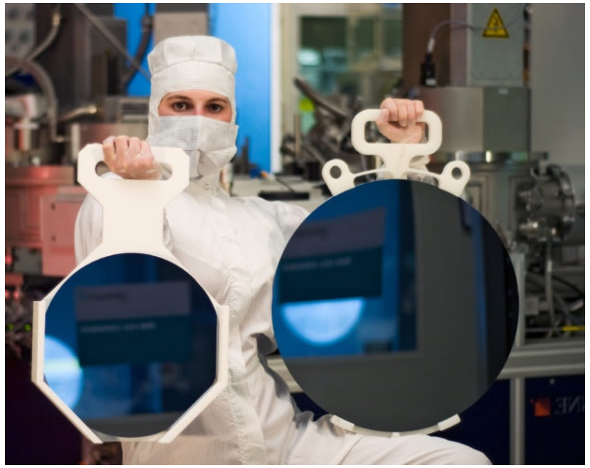
Scalable Production Technique



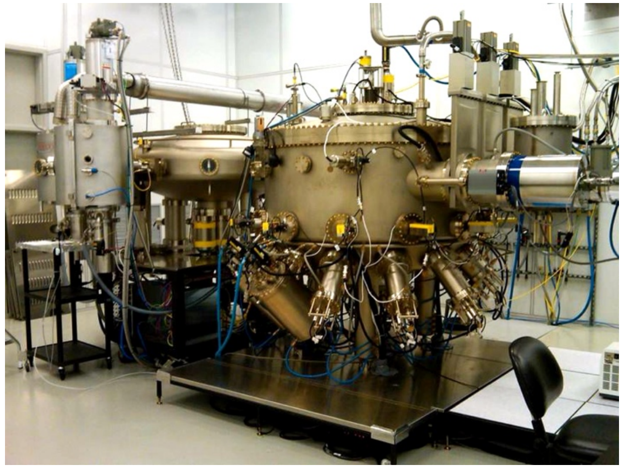
- Leverage semiconductor infrastructure for LIGO-scale optics
  - high-uniformity epitaxial growth on large-diameter substrates
  - void-free direct bonding of crystalline semiconductors
  - commercial tools available for LIGO-relevant mirror sizes

Scalable Production Technique

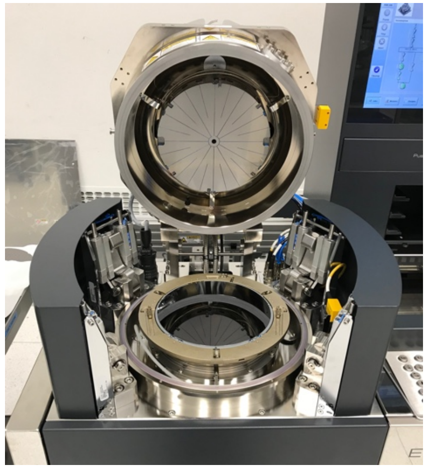
GaAs wafers: 20 → 40 cm



Epitaxy: 30 → 40 cm



Bonding: 45 cm



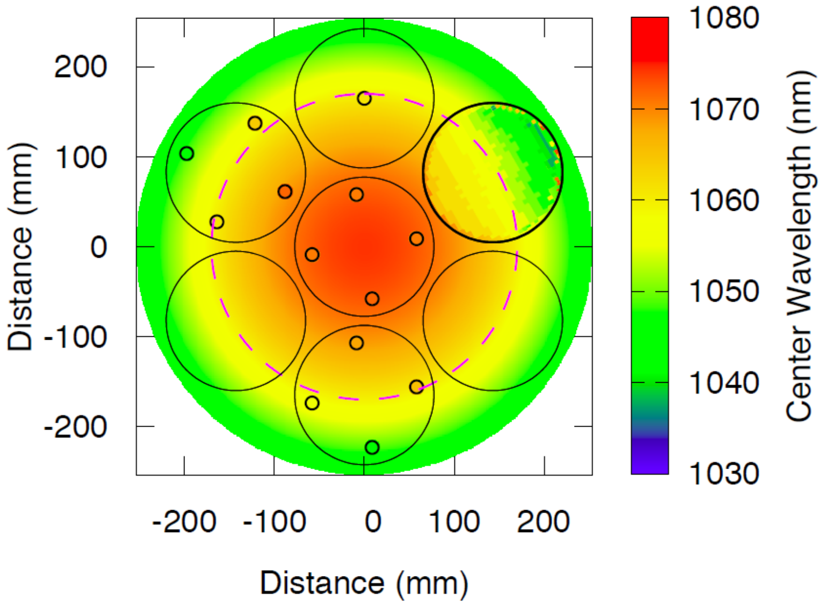
- Crystalline coatings limited to ⌀20 cm, three areas to scale
  - commercial GaAs wafers currently available up to 20-cm diam.
  - epitaxy qualified for wafer sizes of 30 cm (~50-cm chamber diam.)
  - semiconductor direct bonding demonstrated to diam. of 45 cm

LIGO-Scale GaAs Wafers

- Promising discussions with Freiberger Compound Materials
  - currently produce GaAs wafers up to 20-cm diameter
  - VGF crystal growth capabilities up to ~40-cm max diameter
  - "waferizing" processes must be scaled up (main cost driver)
- Estimated 2 year timeline and total cost of ~$5M

Step 2: LIGO-Scale Epitaxy

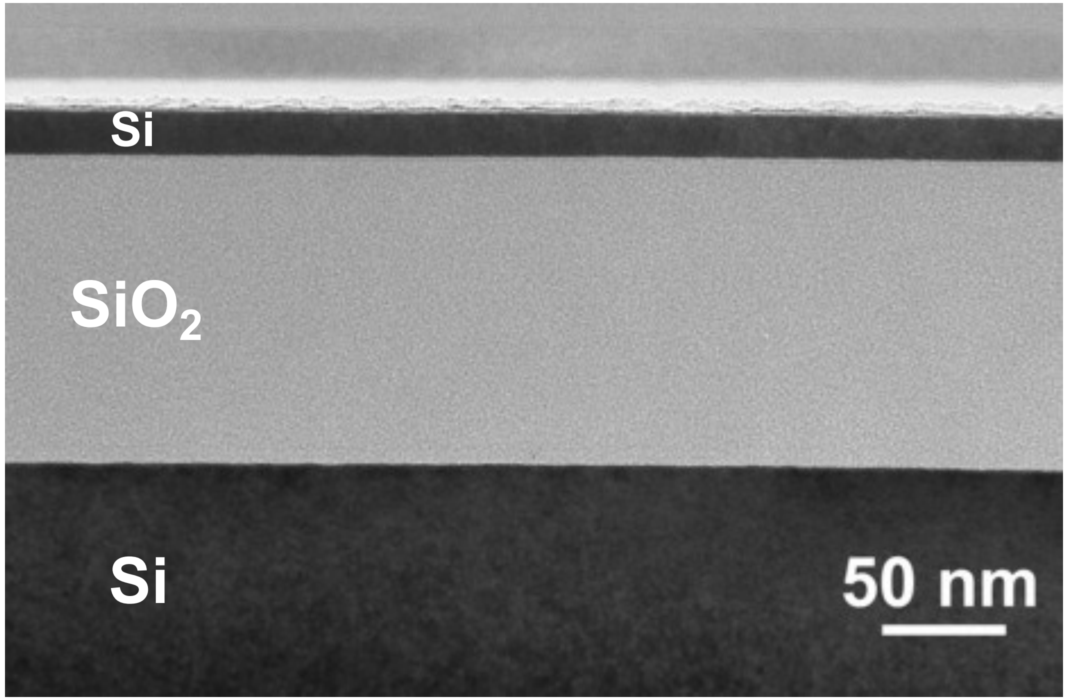
- Ongoing discussions with external epi foundries (US based)
  - two options for production MBE reactors:
    - Veeco Gen2k or Riber7000/8000
  - LIDAR and facial recognition is rapidly changing market
- Estimated 3-4 year timeline and total cost of ~$7M-10M



Step 3: LIGO-Scale Bonding

- Electronic Visions Group, key vendor for semicon. bonding
  - currently offer a production tool for 45-cm SOI manufacturing
    - SOI: silicon on insulator, wafers for microwave electronics
  - designed for 1-mm thick subs., must be modified for optics

Estimated 3-4(?) year timeline and total cost of ~$10M



Exploring 3 loss angles of AlGaAs

Elasticity Matrix (Cubic Crystal — Voigt Notation)

$$\begin{bmatrix} C_{11} & C_{12} & C_{12} & 0 & 0 & 0 \\ C_{12} & C_{11} & C_{12} & 0 & 0 & 0 \\ C_{12} & C_{12} & C_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{44} \end{bmatrix}$$

$C_{11} = 118$ GPa

$C_{12} = 55.9$ GPa

$C_{44} = 58.2$ GPa

There should be a loss angle associate with each of the elastic constants

$$\phi_{11} \;\; \phi_{12} \;\; \phi_{44}$$

Steve Penn LIGO DCC - G1900684

Penn/Harry/Cole:

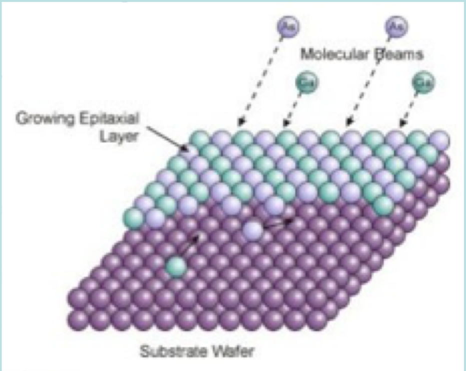
https://arxiv.org/pdf/1811.05976.pdf

$\phi_{\mathrm{Bulk}} = (5.33 \pm 0.03) \times 10^{-4}$, with $\phi_{\mathrm{Shear}} = (0.0 \pm 5.2) \times 10^{-7}$

Fejer/Penn/Harry rechecking effect of thermoelastic contribution – these numbers are overly pessimistic!

AlGaP crystalline mirror technology

Crystalline coatings – GaP growths underway



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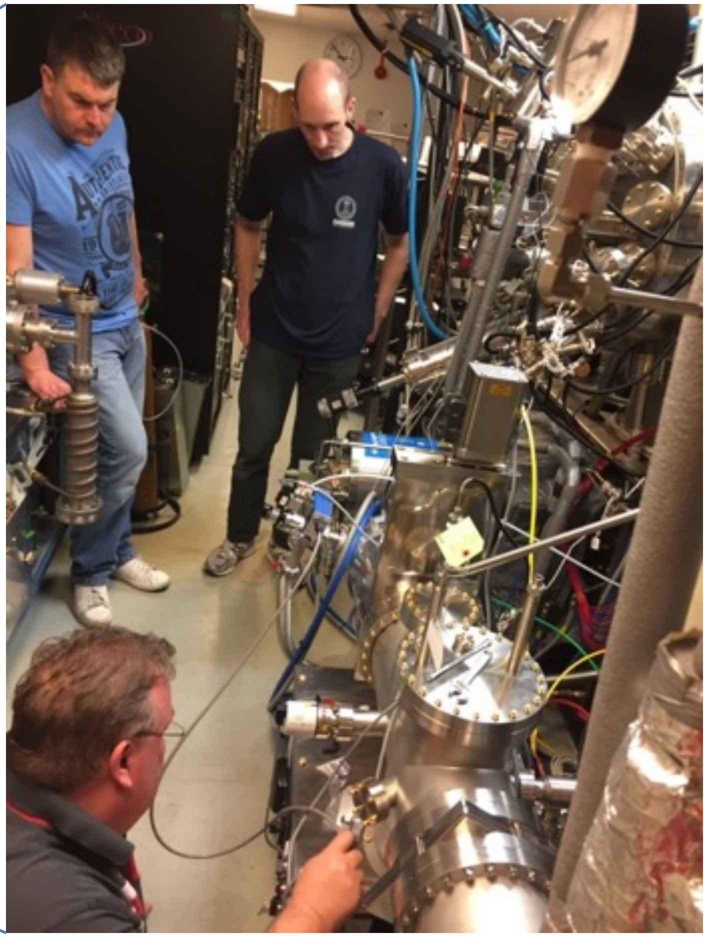
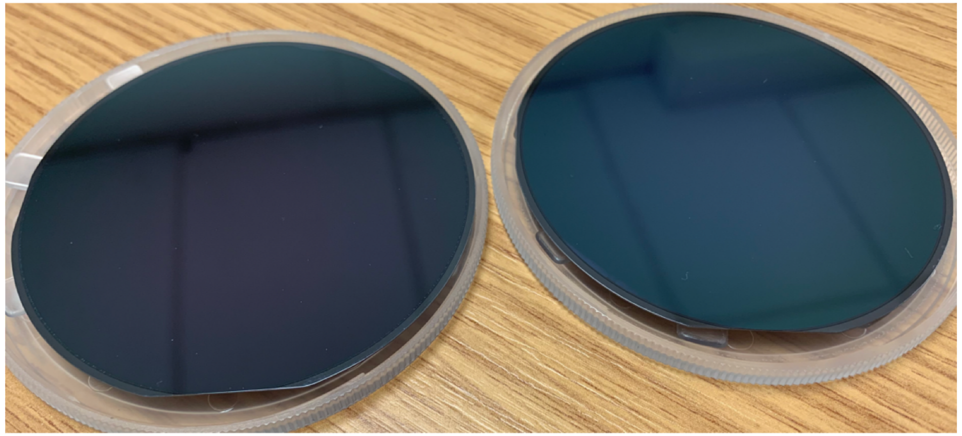
IOP Publishing
Classical and Quantum Gravity
Class. Quantum Grav. 32 (2015) 035002 (10pp)
doi:10.1088/0264-9381/32/3/035002

Measurement of the mechanical loss of prototype GaP/AlGaP crystalline coatings for future gravitational wave detectors

A V Cumming[1], K Craig[1], I W Martin[1], R Bassiri[2], L Cunningham[1], M M Fejer[2], J S Harris[2], K Haughian[1], D Heinert[3], B Lantz[2], A C Lin[2], A S Markosyan[2], R Nawrodt[3], R Route[2] and S Rowan[1]

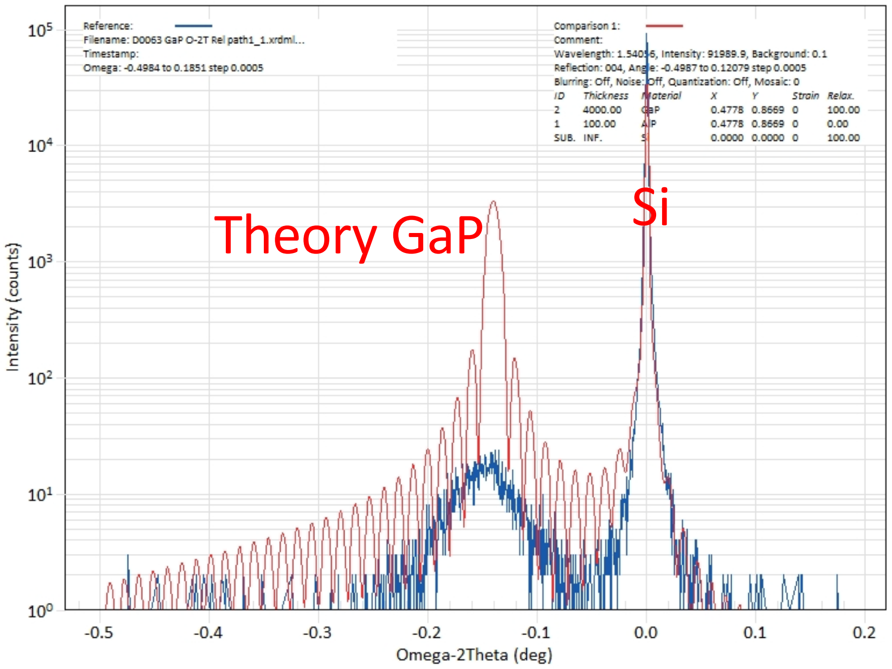


AlGaP crystalline mirror technology



300nm GaP coatings on Si

XRD



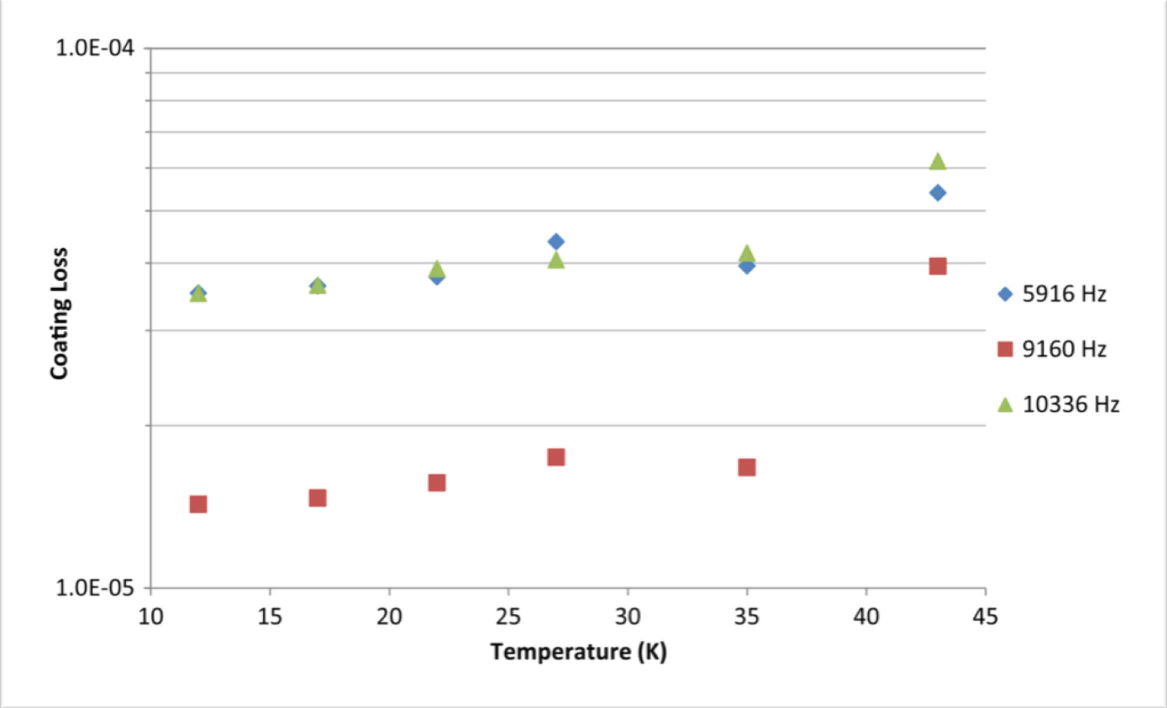
measured GaP

GaP and AlGaP/GaP loss:

Murray et al., Phys. Rev. D 95 (2017) 042004

Coating	Average coating mechanical loss ($\times 10^{-4}$) 14 K	20 K	120 K
GaP	0.39 ± 0.08	0.27 ± 0.02	0.77 ± 0.07
Ta_2O_5	9.0 ± 1.0	10.7 ± 1.3	5.2 ± 0.3

Cumming et al., Class. Quantum Grav. 32 (2015) 035002



MBE

AlGaAs

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Others?!?!

- AlGaN

Growth on Al_2O_3, GaN or AlN.

Issues of quality of films on Al_2O_3 cited by Novikov et al. Journal of Vacuum Science & Technology B 34, 02L102 (2016)

Common challenges:

- electro-optic and piezoelectric effects (initial discussion Abernathy T1400726)
- scaling (Cole estimated ~$40M for GaAs substrate + MBE + bonding tool)
- Mechanical loss at RT on crystalline substrates
- Scatter and absorption evaluation, effect of defect, large area
- Who is doing the work? (how much will industry drive, how much do we need to do)?

discussion...