Macroscopic Characterization for the Center for Coating Research

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CCR A+ Timelines

- 28-34 months for an A+ candidate. 112 - 136 weeks.
- Shoot for 100 weeks of experiments, with follow-up
- Can we deposit a run/week for 100 weeks?
- What are the coating quality measurements at deposition?
- Time required for RT and Cryo Mechanical Loss
- Annealing studies: Timeline and measurements
- **AlGaAs Production and Testing**

Deposition Options

- Atomic Layer Deposition (H),
- Dual Ion Beam Sputtering / Ion Beam Sputtering(H),
- High Power Impulse Magnetron Sputtering (HiPIMS) (H),
- Magnetron Sputtering (H),
- Gas Flow Sputtering
- Plasma Enhanced Chemical Vapor Deposition (PECVD) (Microwave, RF, both),

PostDeposition Characterization

- Rutherford Back Scattering for new compositions
- Raman for Bond Angle distribution,
- X-ray Diffraction for amorphous/crystallization
- Fluctuating Electron Microscopy for medium range order
- Surface scans available: AFM, STM, Raman/AFM, coupled IR/AFM, SEM, TEM, STEM

Mechanical Loss Measurements

- Room Temperature Mechanical Loss
  - Multimodal Nodal Suspension,
  - Multimodal Welded Suspension (when needed)
- Cryogenic Mechanical Loss
  - Multimodal
    - Array of Cantilevers or DPO's
    - Nodal Silicon Disk (Gentle or Nodal Vise)

Annealing and Post-Annealing Measurements

- Annealing
  - Gas environment: Air assumed
  - Peak temperature and Ramp-down rate
- Post Annealing: XRD, Raman, FEM
- Mechanical Loss: RT, Cryo
- *Do we need to do repeat annealing or can we monitor in situ?*

Follow-up Measurements

Optical Losses

- Scattering at Fullerton
- Absorption at Stanford

Mechanical Losses

- Thermo-Optic at Whitman
- Direct Thermal Noise at MIT

Data Challenges

Parameter Space is large

- Materials: Tantala, Titania, Zirconia, …
- Doping level
- Substrate temperature
- Ion Assist energy & current
- Annealing peak temperature and cool down rate
- We need to perform an informed walk through parameter space.
- Requires fast turnaround in deposition and characterization.
- Partition into defined studies for publication

Data Challenges

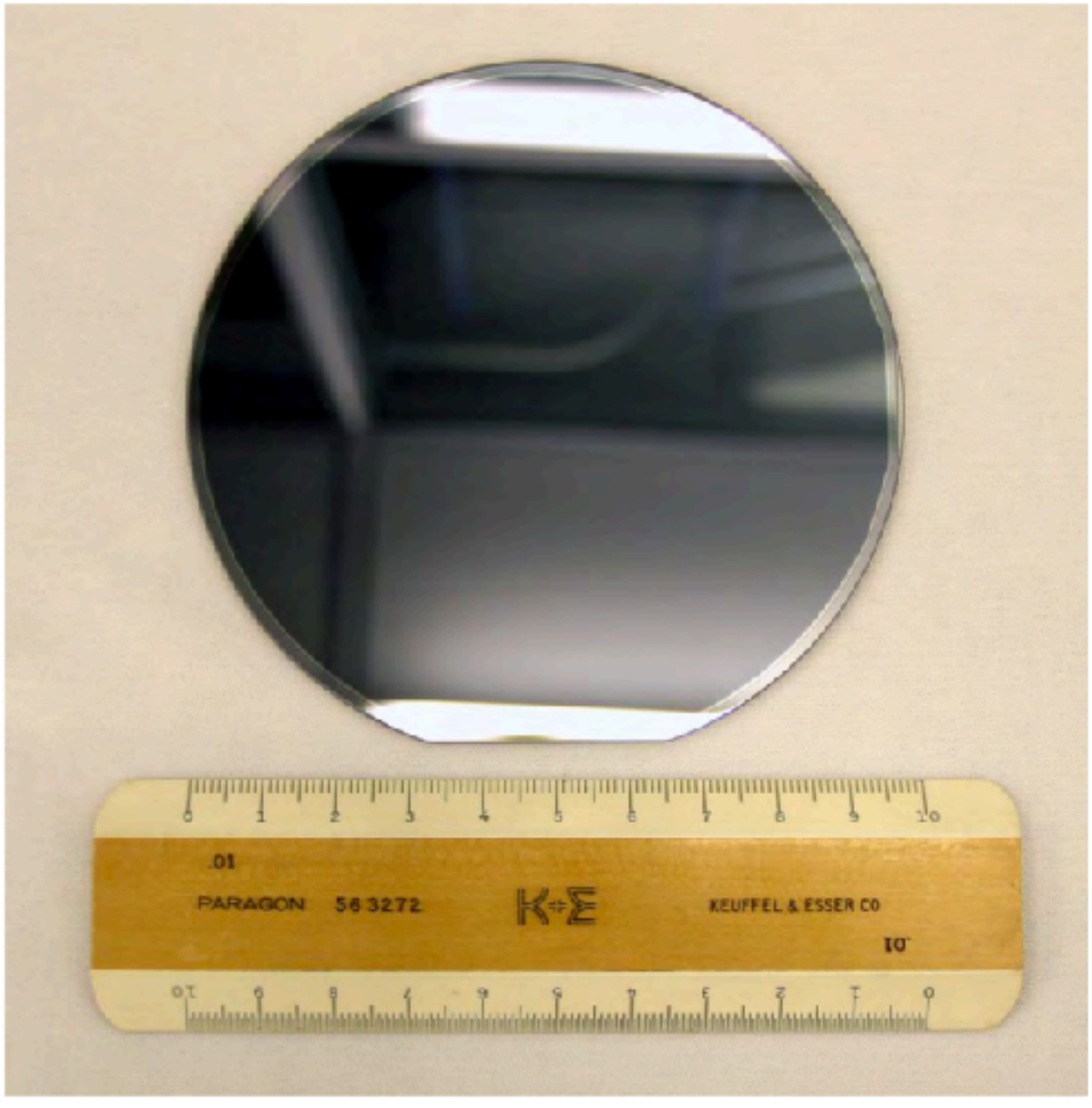
Database required.

- Single ID method
- Mandatory tracking
- Easy, accessible results upload & access
- Data Summary and display
- Raw data upload??

Data driven research plan requires data

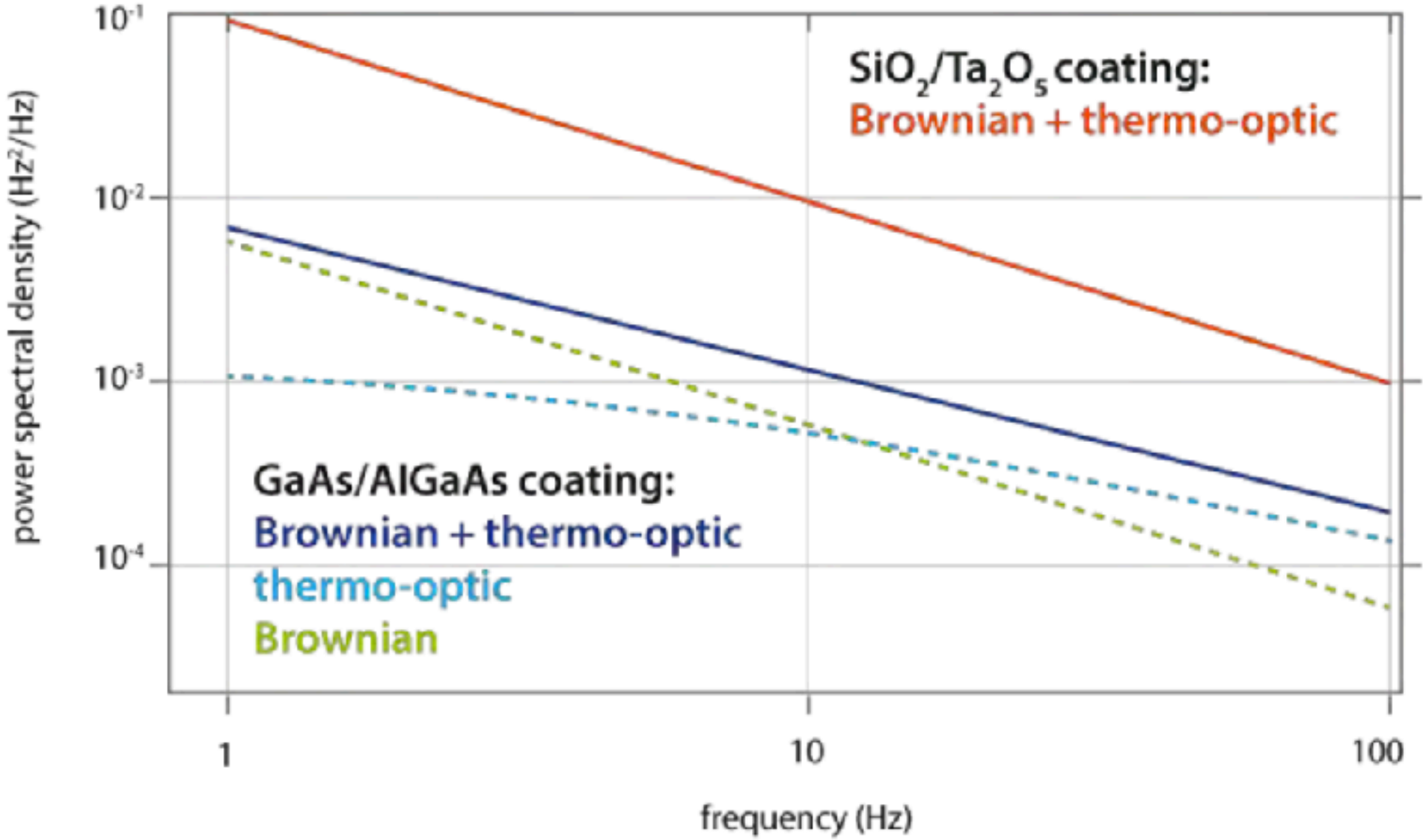
Additional Capabilities

- High optical quality in the mid-infrared (2-5 μm)
  - initial tests with Jun Ye's group reveal scatter + absorption losses at the ~100 ppm level (3000 nm)
- High thermal conductivity
  - ~30 W/m*K (IBS: ~1)
- Transfer to curved surfaces
  - minimum ROC: 100 mm
  - larger ROC is easier
- 100+ mm Ø direct bonding
  - void free over entire area
  - bond strengths of ~1 J/m^2



Large area direct bonding:
100-mm diameter GaAs on silica

Reduced Brownian Noise



- Tenfold reduction in mechanical dissipation at room temperature
- Further 10 × improvement upon cooling to cryogenic temperatures

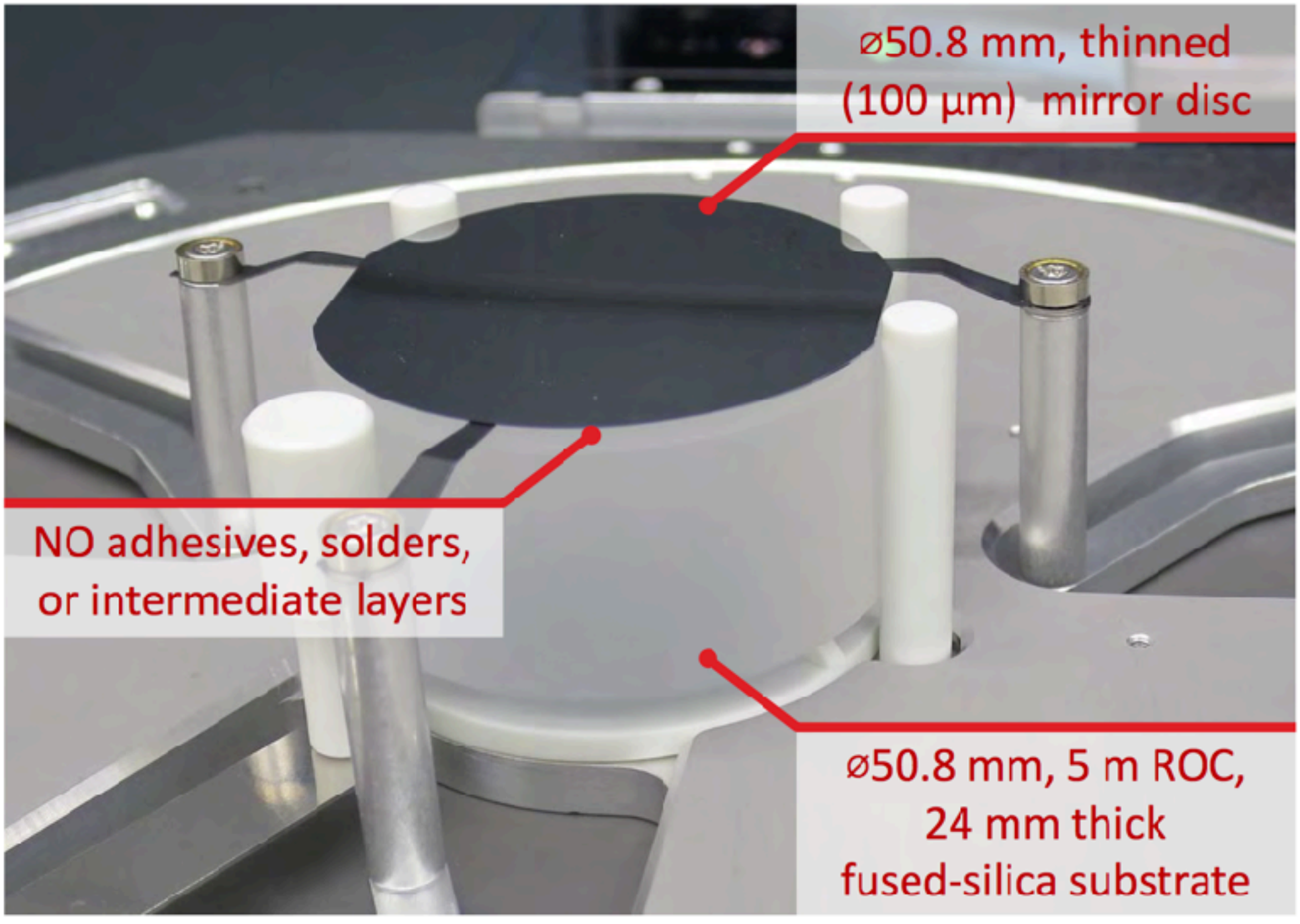
G. D. Cole, W. Zhang, M. J. Martin, J. Ye, and M. Aspelmeyer, Nature Photonics (2013)

Summary

Substrate-transferred crystalline coatings simultaneously exhibit **excellent optical and mechanical quality**

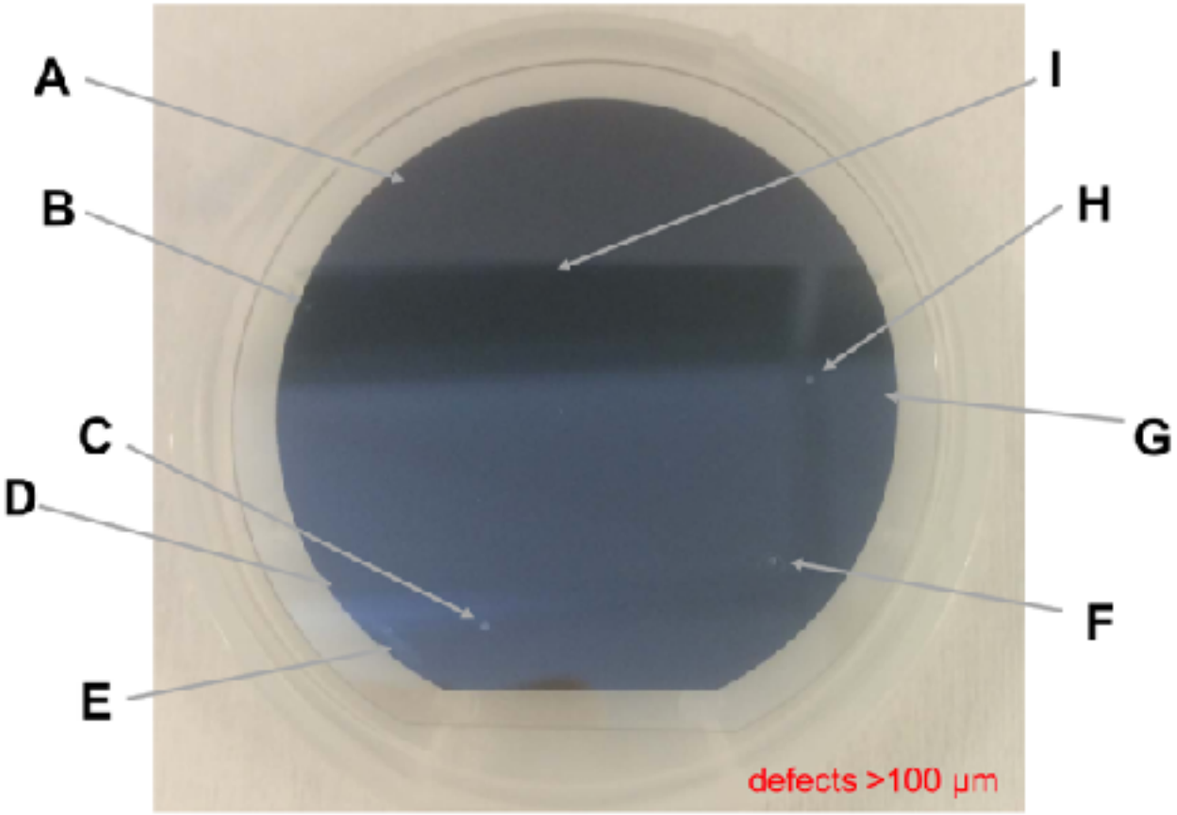
- Damping reduction of 10-100× compared with IBS films
  - IBS-deposited Ta_2O_5/SiO_2: typical Q ~3000 ($\varphi_{IBS} \approx 2\text{-}4 \times 10^{-4}$)
  - AlGaAs room temperature Q-value of 4×10^4 ($\varphi_{RT} \approx 2 \times 10^{-5}$)
  - AlGaAs cryogenic performance: Q > 1×10^5 ($\varphi_{min} \approx 4.5 \times 10^{-6}$)
- Minimal scattering loss and optical absorption
  - absorption verified at < 1 ppm, scatter loss < 5 ppm
  - measured finesse >2×10^5 at 1064, 1156, 1397, and 1550 nm
- Potential for ppm-level optical losses in the MIR
  - optical absorption verified to be <5 ppm at 3.7 μm

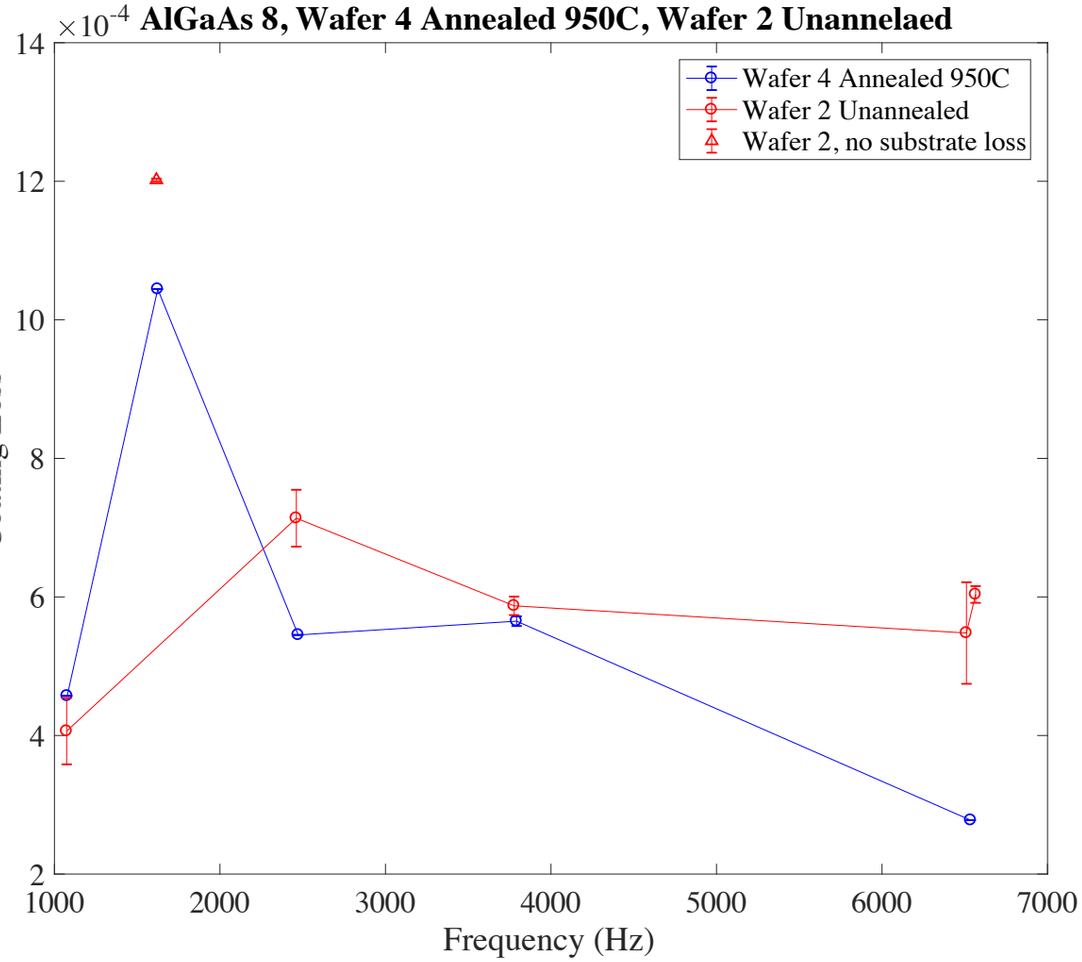
Substrate-Transfer – Direct Bonding



AlGaAs Challenges

- Defect density is still too high. Several / 3” sample
- Interface losses still 10x too high





Conclusions

Amorphous Coatings:

- Defined regular set of measurements
    - Post-deposition
    - Mechanical loss: RT and Cryo
    - Annealing:
        - Post-annealing structure measurements
        - Mechanical loss & repeat??
    - Coating Candidates: Optical losses, ThermoOptic, and Thermal Noise
- **Regular, rapid schedule. Results database. Summary analyses.**

AlGaAs studies:

- **Interface losses. Larger AlGaAs / Amorphous coatings**