Amorphous Coatings

Current Status — Future Plans

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Coating Thermal Noise

- Limits the sensitivity for 2nd Generation detectors
- Reduced by changing (in current interferometer design)
  - Form factor: Laguerre-Gauss beams
  - Dissipation in the coating
    - Redesign the coating structure:
      - Etched Refractive layers: *Jena (S. Kroker talk)*
      - Crystalline coatings: *Vienna (G. Cole talk)*
    - **Reduce the loss in Amorphous Coatings**

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Amorphous (Metal-Oxide) Coatings

- Optical Quality
  - Can provide ppm level scattering and absorption
  - Significant History and Industry for these coatings
- Mechanical Quality
  - Dissipation predominantly in material
    - Loss at interface still being explored
  - Material Structure Research: *Determine loss mechanism / Redesign Coating*
    - Theoretical work: *UFlorida & Southern U.*
    - Experimental work:
      - Reduced Density Function to model structure: *Stanford (R. Bassiri talk)*
      - Activation Energy of loss mechanisms: *Glasgow (I. Martin talk)*
  - Optimize Coating Structure: *USannio (R. DeSalvo talk)*
  - **Optimize Coating Materials:** ***Material Selection and Processing***

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Optimize Amorphous Coatings:
Material Properties

- Material Properties: *Ion Beam Sputtering (IBS) process alters properties*
    - Residual stress (compressive)
    - Variable thermal annealing history (reduce stress & absorption)
- Young's Modulus:
    - NanoIndenter: *Glasgow (M. Abernathy)*
    - Ultrasonic reflection: *Embry-Riddle (M. Zanolin, A. Gretarsson)*
- Coating Phi Components
    - Torsional loss in coatings - Test $\phi_\perp$ vs $\phi_{||}$: *American (G. Harry)*

$$S_x(f)_{\mathrm{coating}} = \frac{2k_{\mathrm{B}}T}{\pi^2\, fY}\frac{d}{w_m^2}\left(\frac{Y'}{Y}\phi_{||} + \frac{Y}{Y'}\phi_\perp\right)$$

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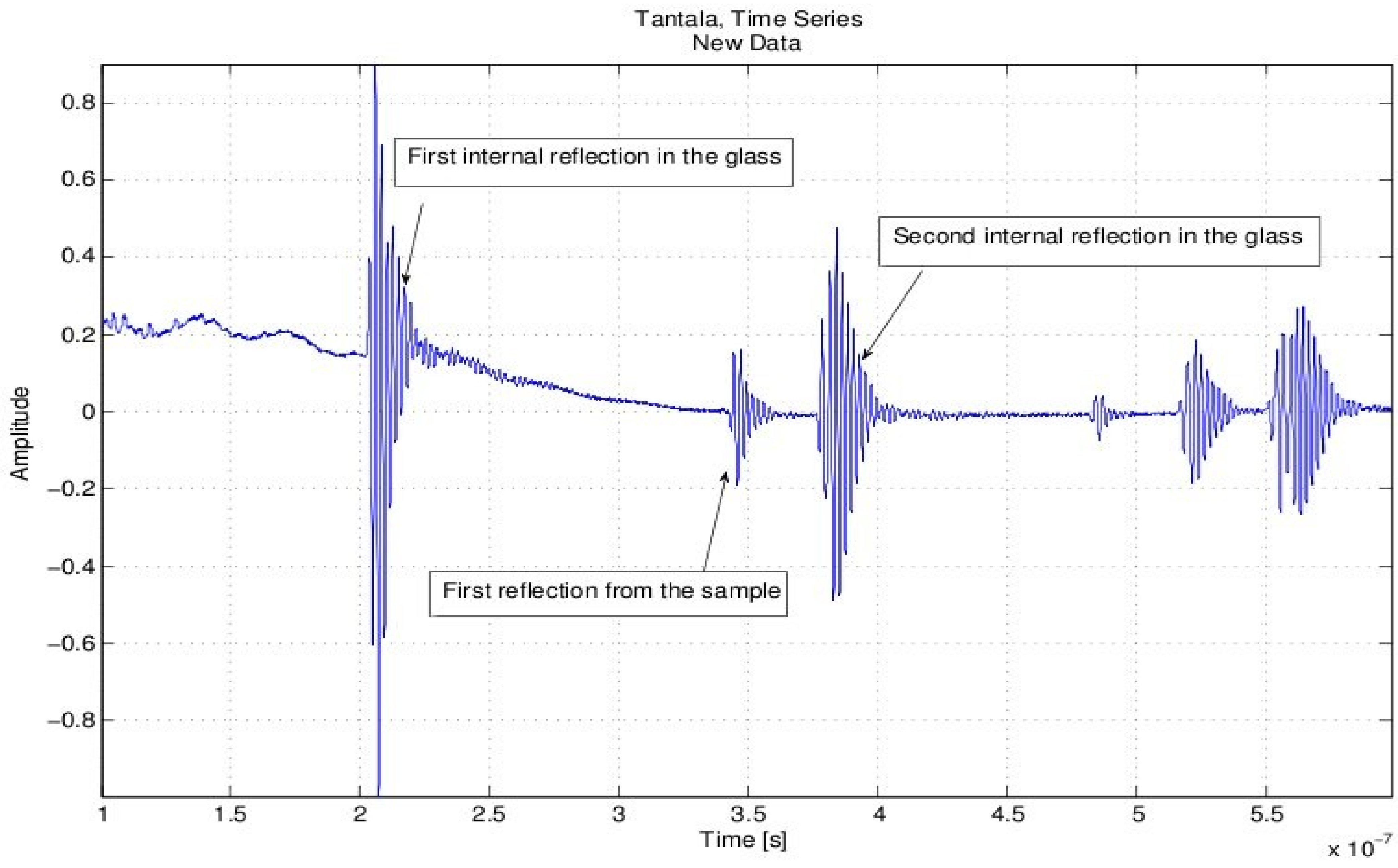
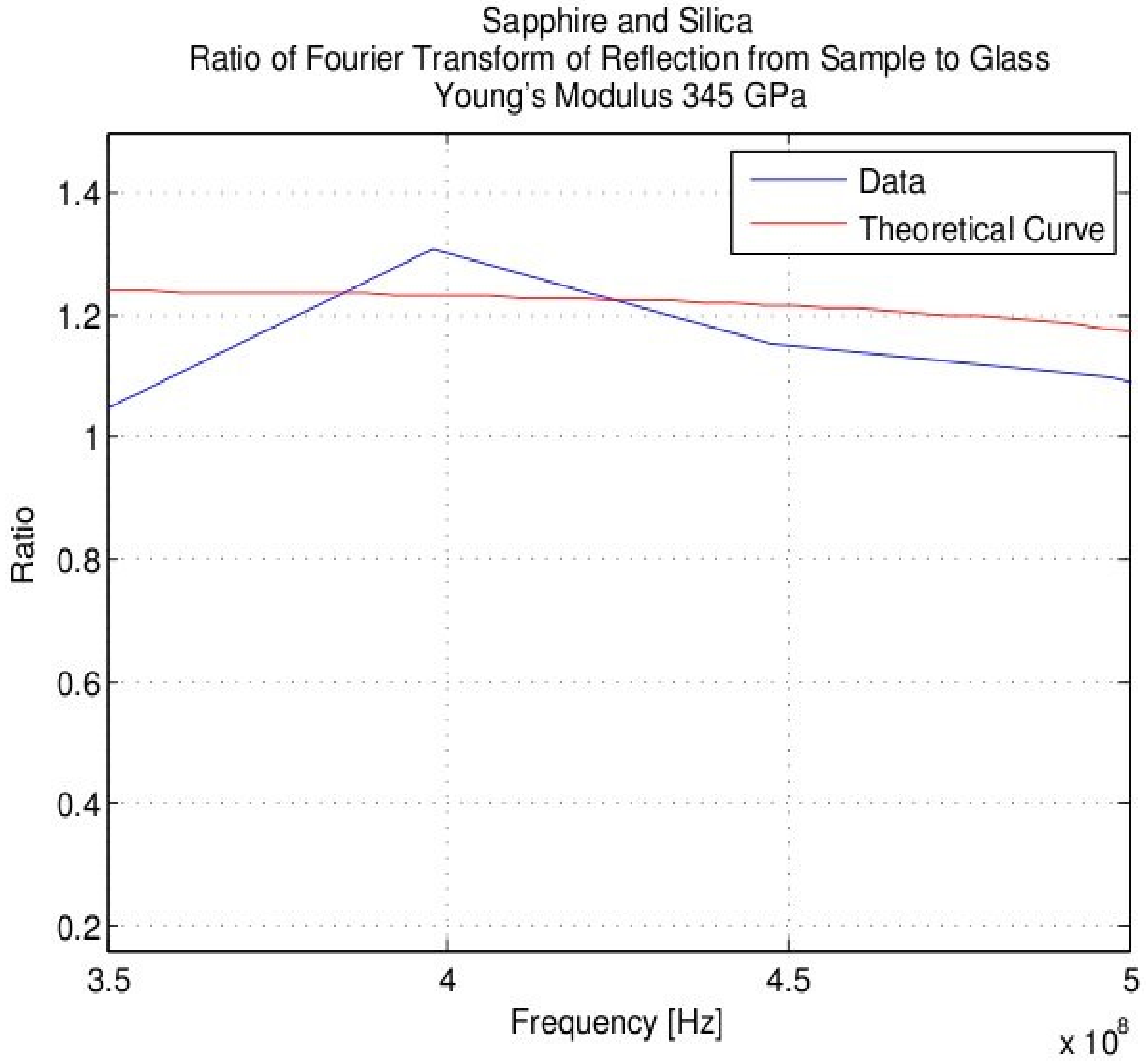
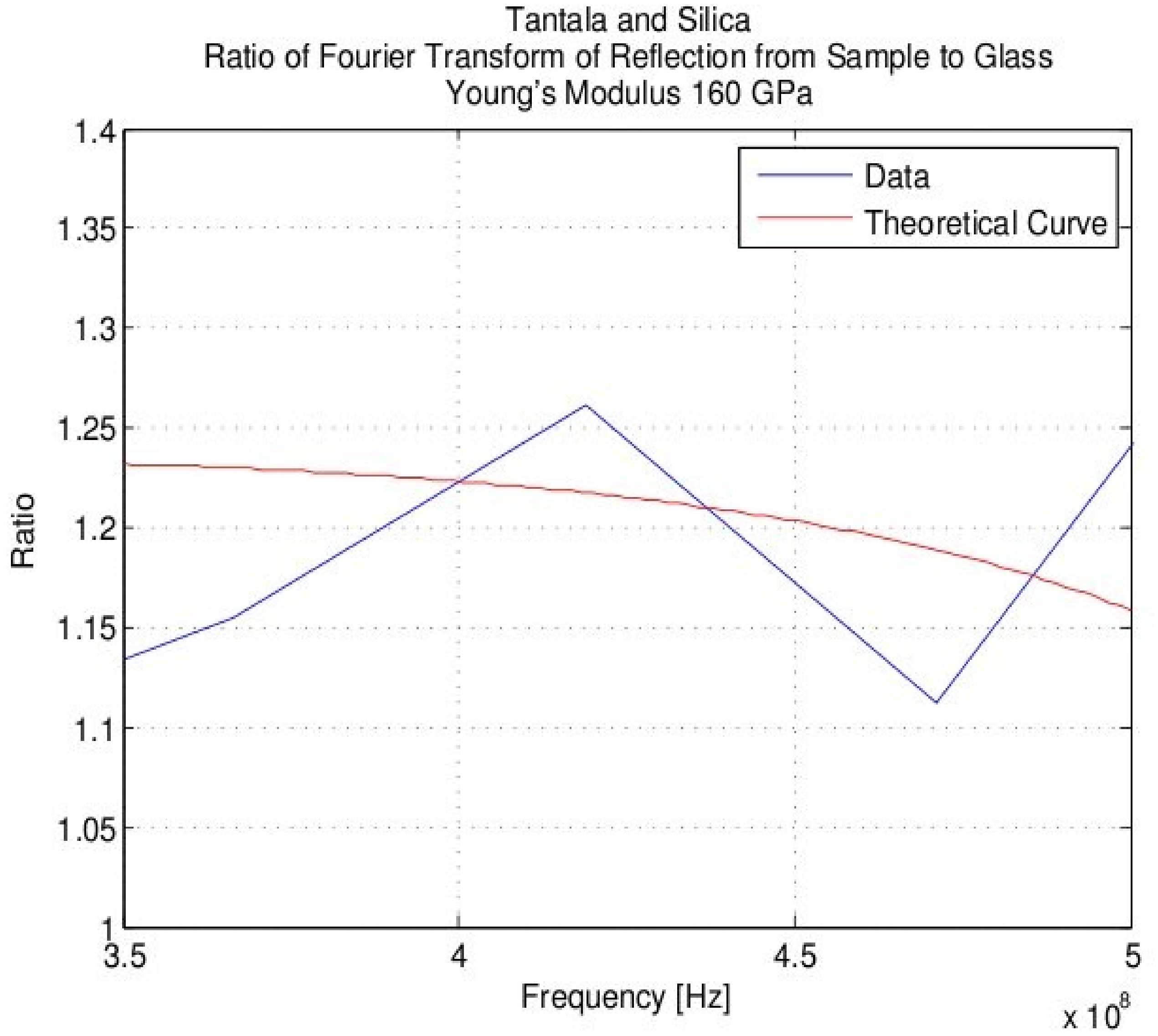
Ultrasonic measurement of Young's modulus of LIGO coatings at ERAU

A.Gretarsson,E.Gretarsson,E.Rhoades, M.Zanolin



Two examples





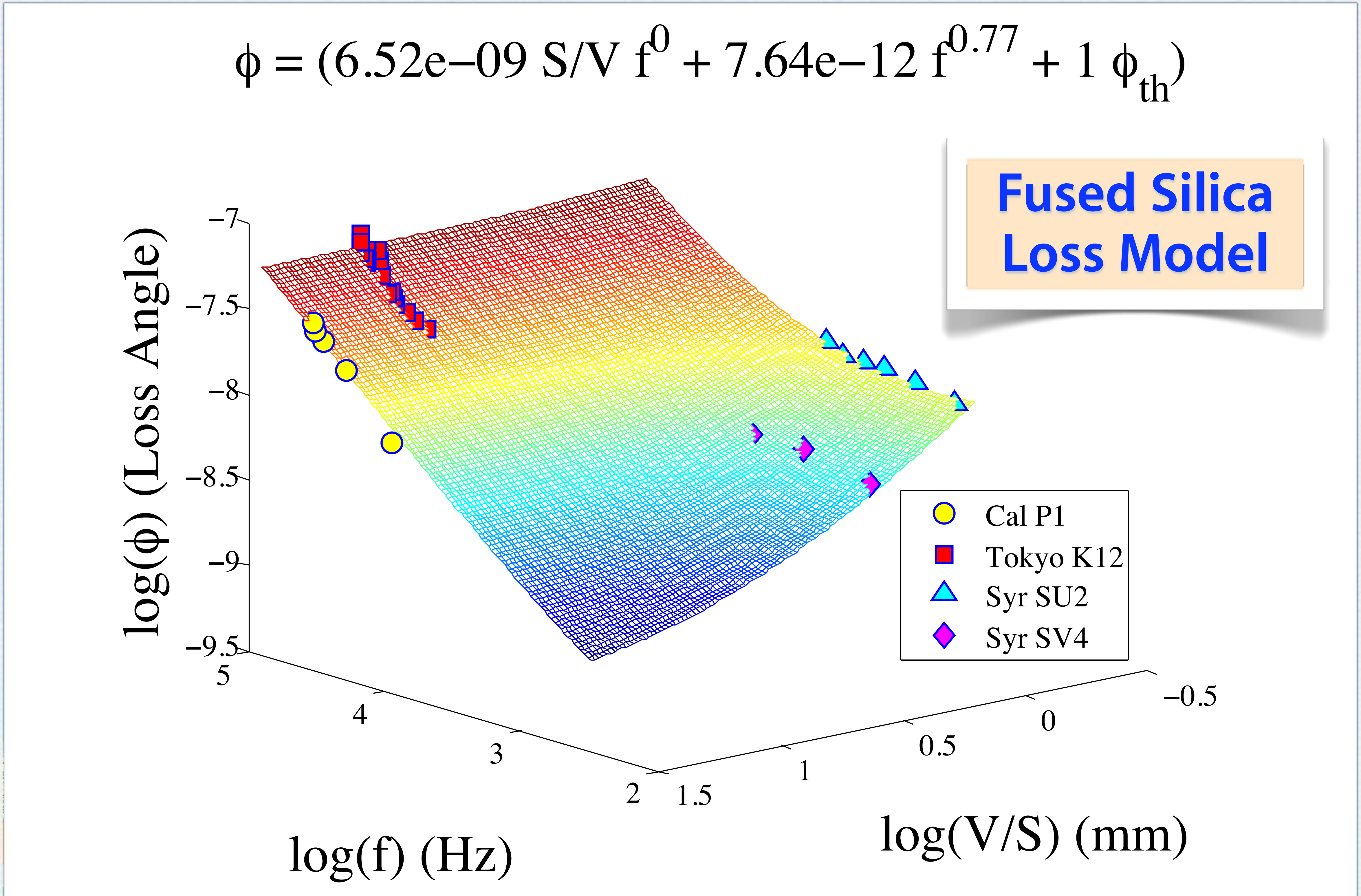
- The two plots show the ratio of the reflection coefficient of a sapphire substrate (left) and a 5 microns Tantala coating on a silica substrate (right) with respect to the reflection coefficient of a silica substrate. The blue curve is the average spectrum of 5 measurements and the red is a theoretical one where the free parameter is the YM of the testing sample (pure sapphire and Tantala coating).The quoted estimate above the pictures is a least square estimate.

Optimize Amorphous Coatings:
Material Selection

- High Index: *Tantala, Titania, … Zirconia, Niobia, Hafnia*
  - Loss as coated are comparable: few x 10^{-4}
  - **Tantala**: Moderately stable (300–400° C), n ≈ 2.1
  - **Titania:** Less stable (200° C). n≈ 2.5
  - **Zirconia:** High Absorption, 10-50 ppm
  - **Niobia:** High loss 4.5 x 10^{-4}
- Doped High-Index Materials:
  - **Titania(20%)-Tantala:**
    - Lowers loss to 2 x 10^{-4}, Stabilizes Titania, index admixture
    - Measurements to 55%-doping under analysis. Proposed 90% run.
  - **Silica-doped (Titania/Tantala/...)**
    - Stabilizes high-index material
    - Lowers index — mixture determines index
    - Little gain in loss

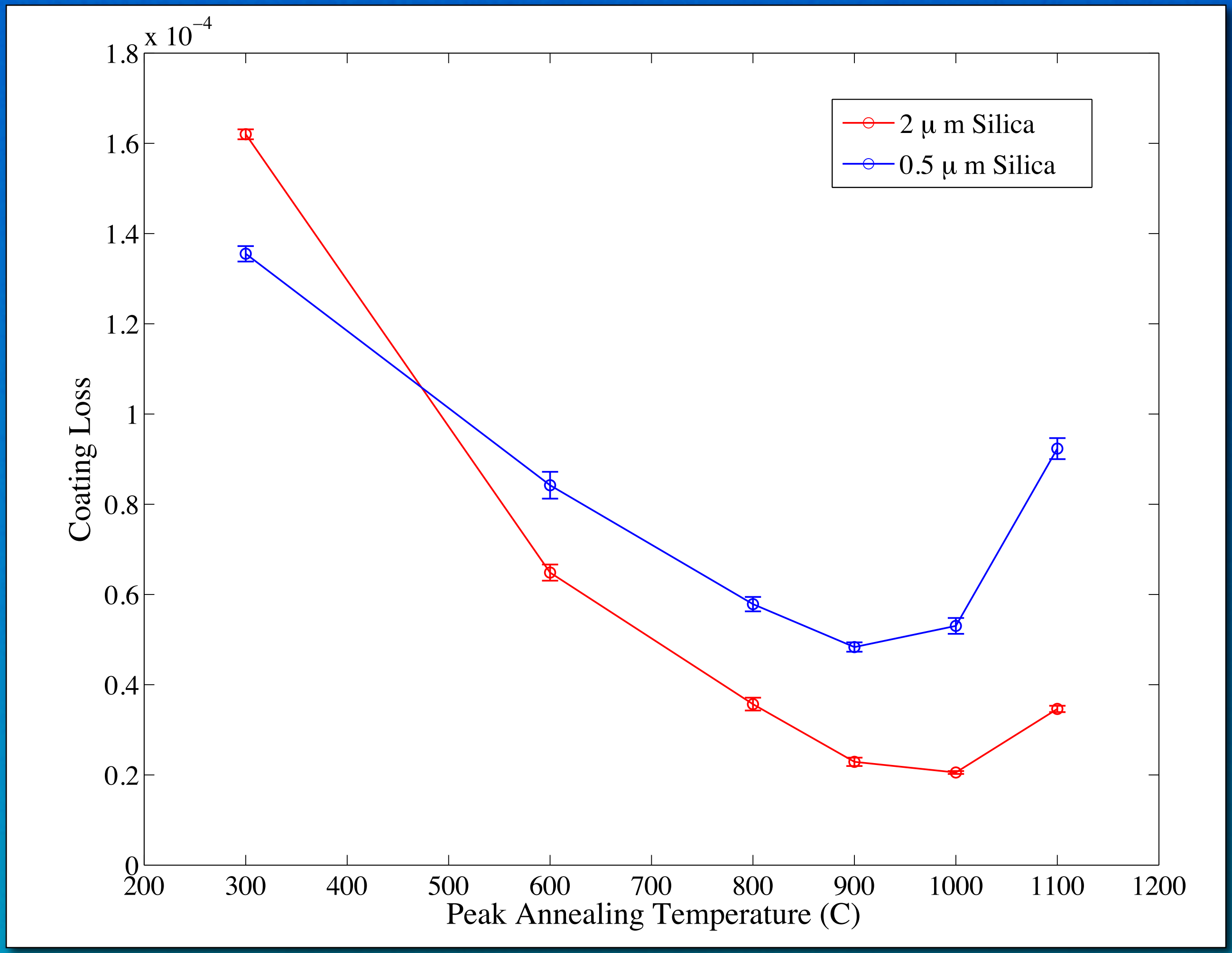
Optimize Amorphous Coatings: Silica

- **Silica:** Loss Model. Lowest loss $\phi \approx 5 \times 10^{-9}$
  - Coating loss is well measured as bulk and as a coating.



Optimize Amorphous Coatings:
Annealing

- Annealing: *Provided that the sample remain amorphous*
  - Reduces mechanical loss by a factor of few to several depending on the material. (8x for 2 micron silica)
  - Reduces optical absorption by equally larger factor (zirconia reduced from 100 ppm to 10 ppm by 900° C)



Optimized Coatings via Annealing

1) Select, or mix, a high-index coating material

    1) Match the CTE to silica (or low-index material)

    2) Dope against crystallization

2) Make a quarter-wavelength multilayer

3) Anneal to 1000° C

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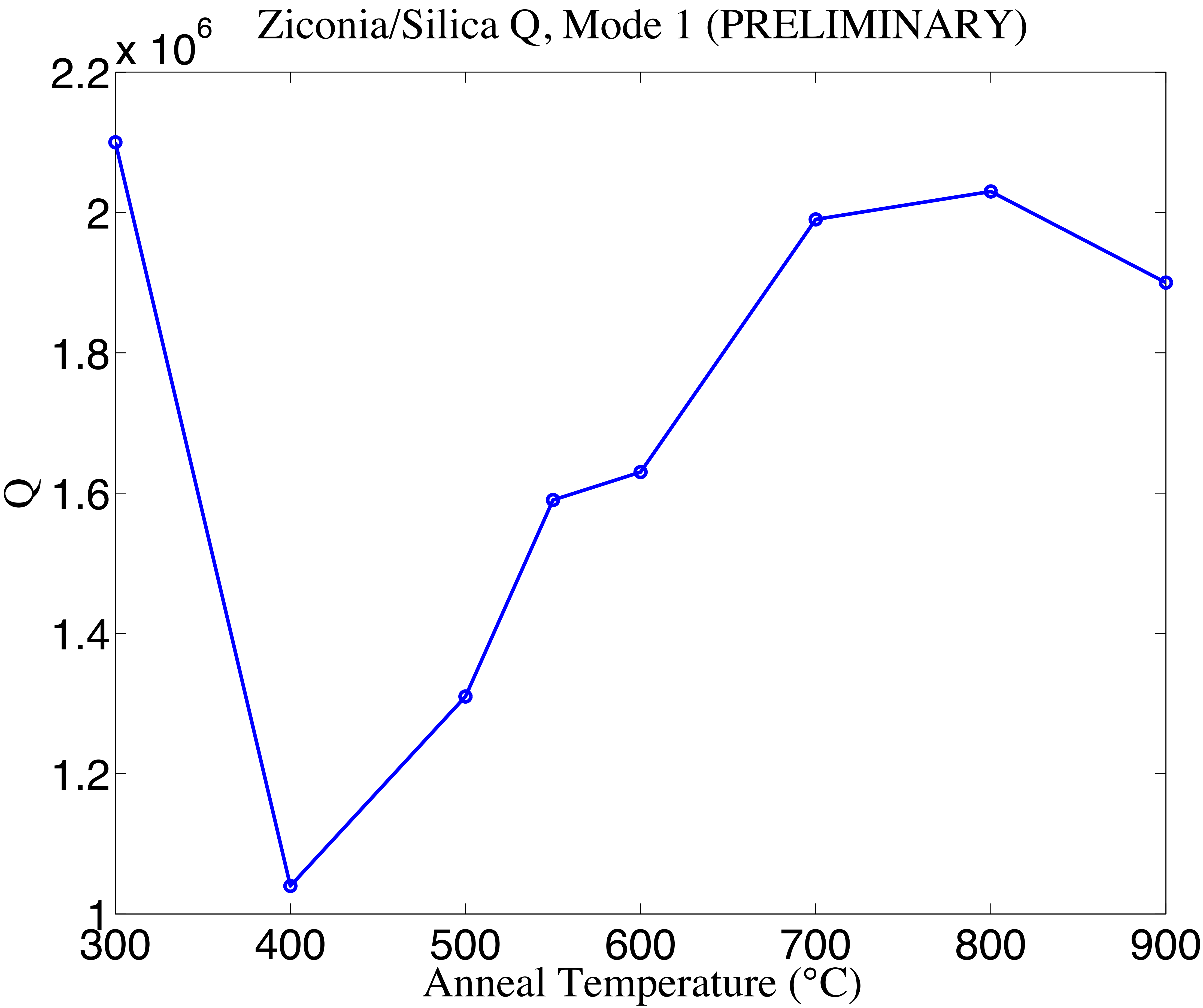
Zirconia/Silica Coating

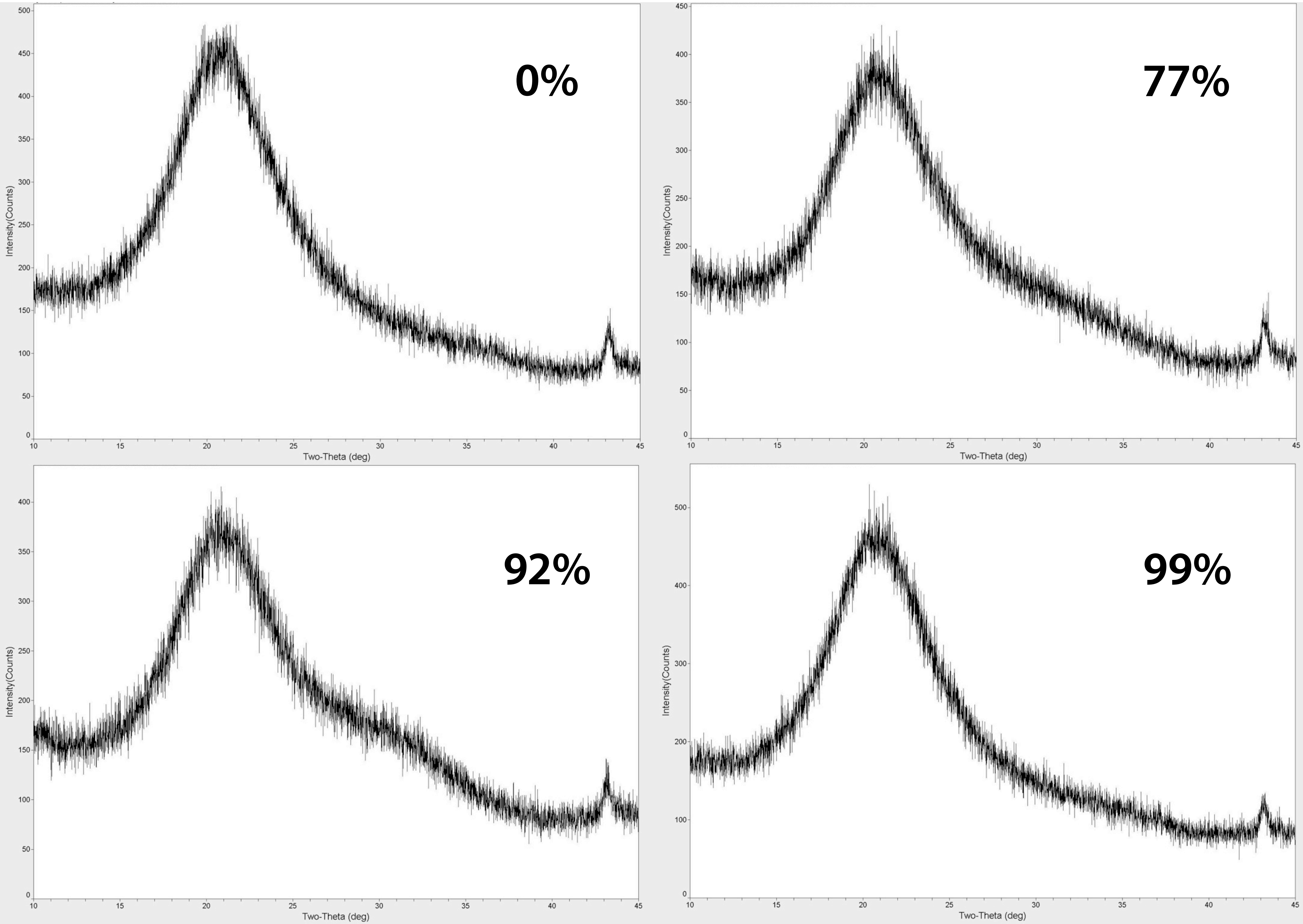
(2 λ/4 doublets)

- Annealed up to 1000°C
- No peeling, bubbles, crazing, or loss of adhesion.
- At 1000° C, excess scatter detectable with naked eye.
- X-ray diffraction shows crystallization
- Scatter only 10x than superpolished sample
- Absorption ≈< 10 ppm

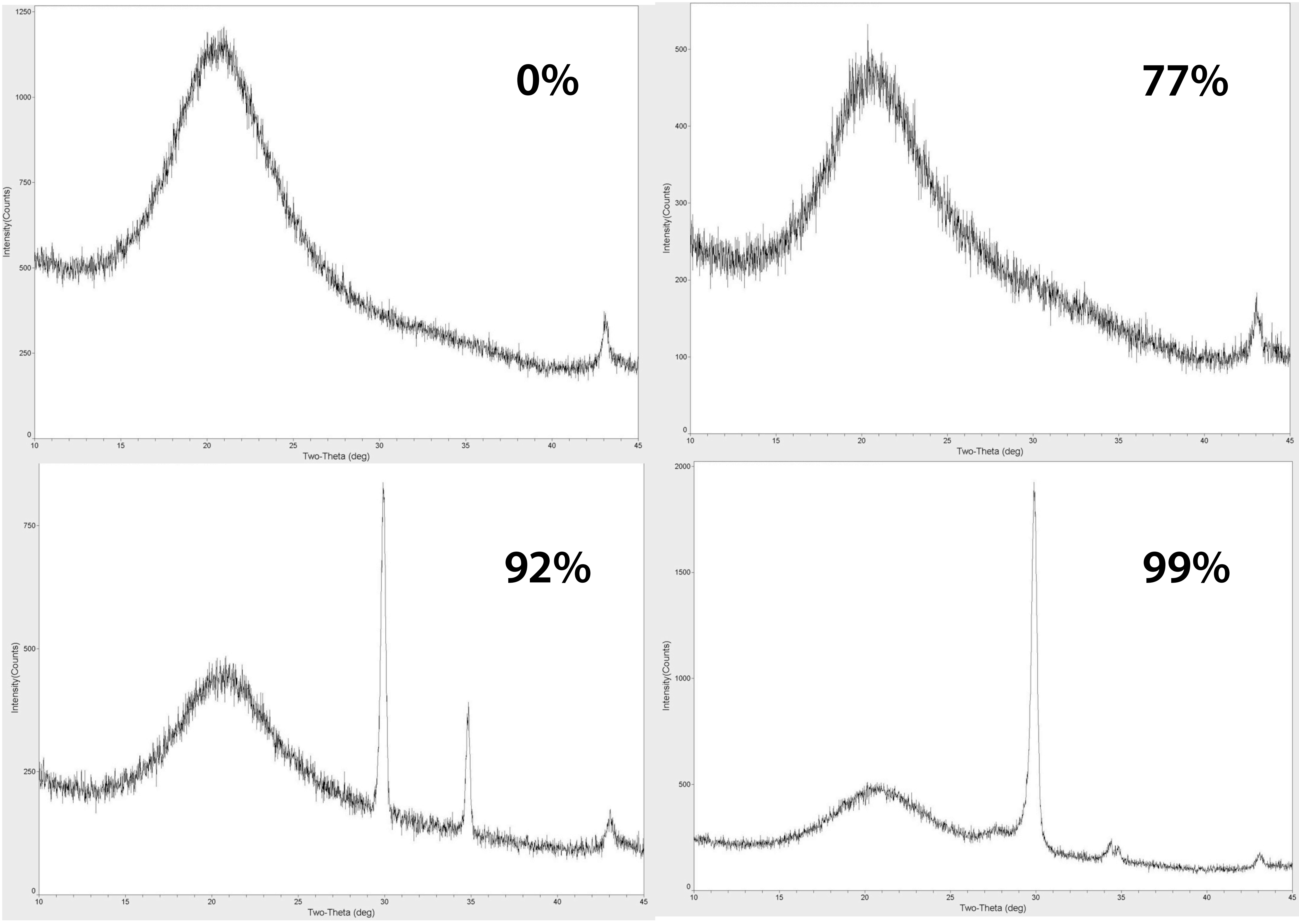


Ziconia/Silica Q, Mode 1 (PRELIMINARY)
x 10^6
2.2
2
1.8
1.6
1.4
1.2
1
Q
300
400
500
600
700
800
900
Anneal Temperature (°C)

X-ray Diffraction of Silica-doped Zirconia, Anneal ≈ 300° C



X-ray Diffraction of Silica-doped Zirconia, Anneal ≈ 600° C



Summary

- IBS produced Amorphous coatings can provide the required optical qualities for Advanced Generation of detectors.
- Current coating loss "acceptable", but should be improved
- Considerable effort being devoted to characterize and understand the physical characteristics, structure, and loss mechanisms of amorphous coatings.
- Doping has provided the most significant improvement (≈40%) in a complete multilayer coating (Ti-doped-Tantala/Silica)
- Annealing has shown improvements of few-several in the loss.
- Silica-doped Zirconia is a test of principle.

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