Atomic structure investigations of amorphous coatings

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Introduction

- Reducing coating thermal noise is key challenge for future detectors

temperature coating thickness

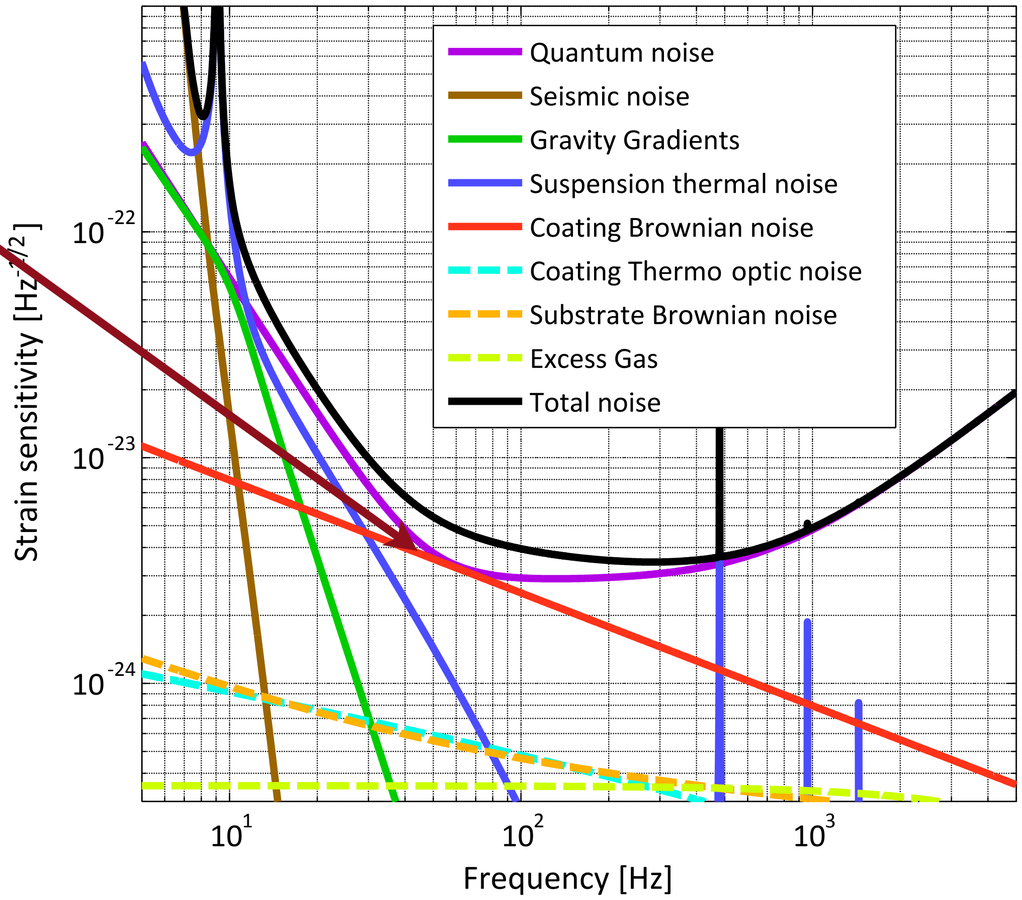
$$S_x(f,T) \approx \frac{2k_B T}{\pi^2 f} \frac{d}{w^2 Y} \phi \left(\frac{Y'}{Y} + \frac{Y}{Y'} \right)$$

laser beam radius coating mechanical loss

- Number to beat:
  - Mechanical loss Ti:Ta_2O_5 = 2 x 10^{-4}

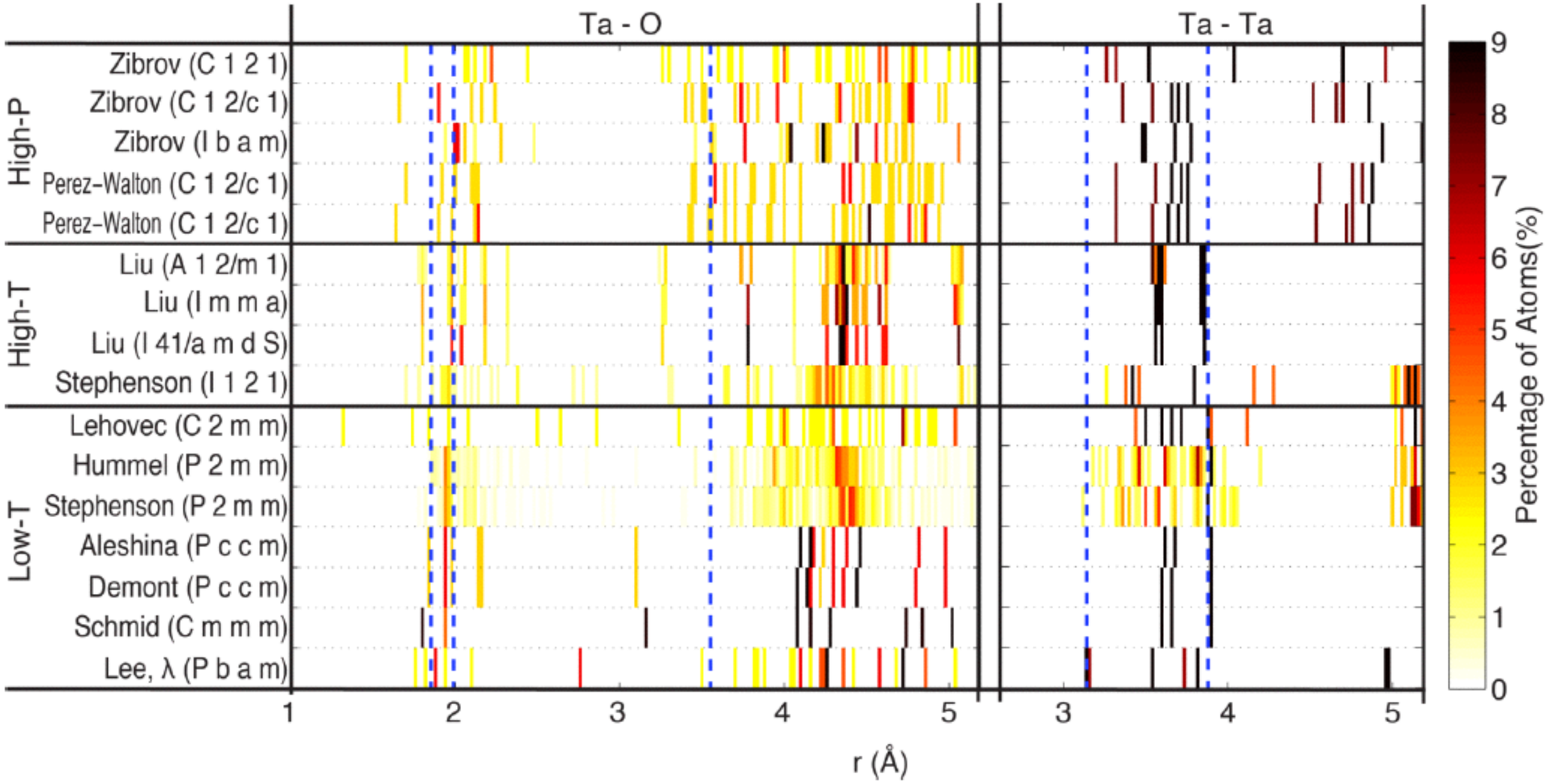
- **Changes in mechanical loss are the result of changes in atomic structure**

aLIGO noise budget (GWINC)



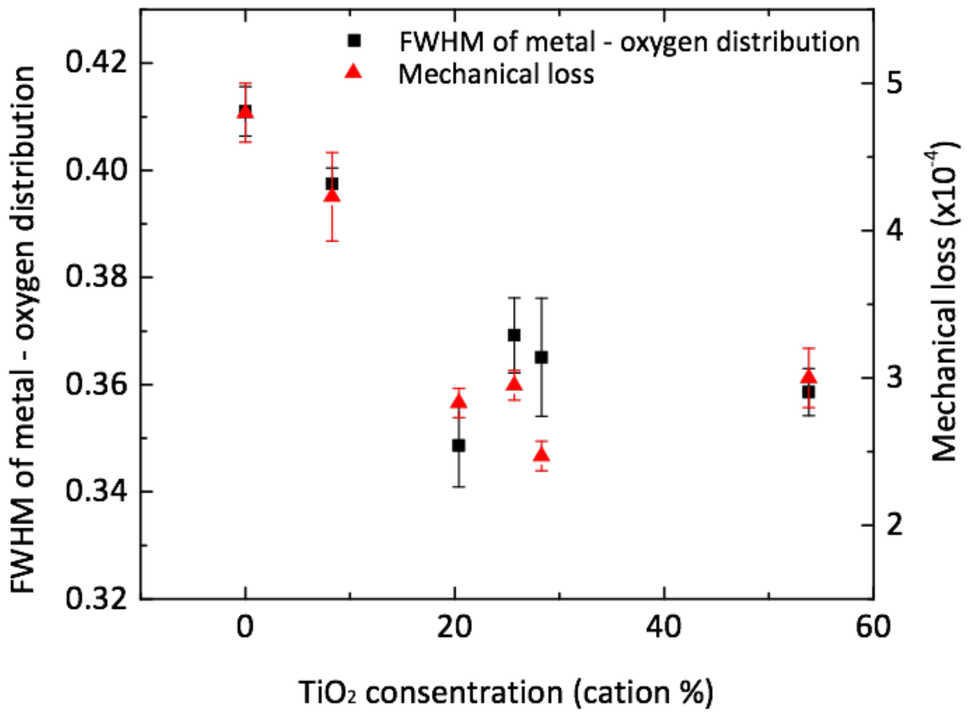
- Measure structure at the short (< 0.5 nm) and medium range (> 0.5 nm)

Tantala: order and disorder

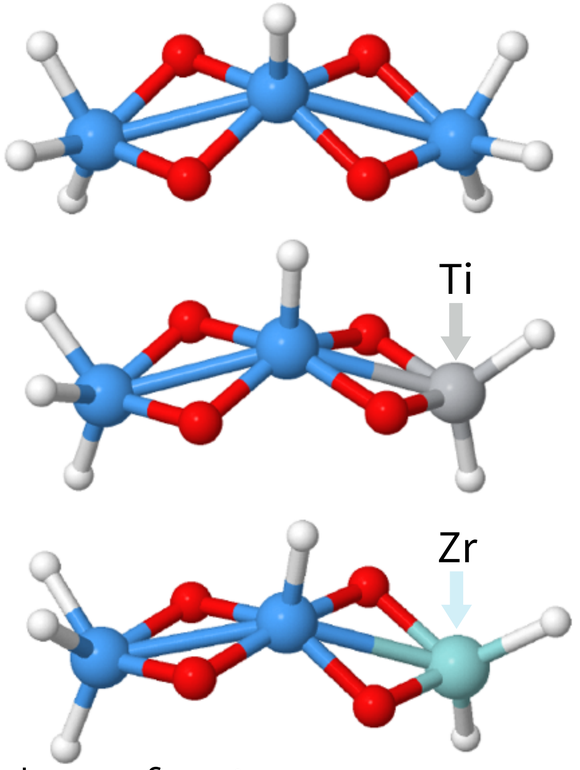


[R Bassiri et al, APL Materials, **3**, 036103 (2015)]

Tantala: order, disorder and mixing



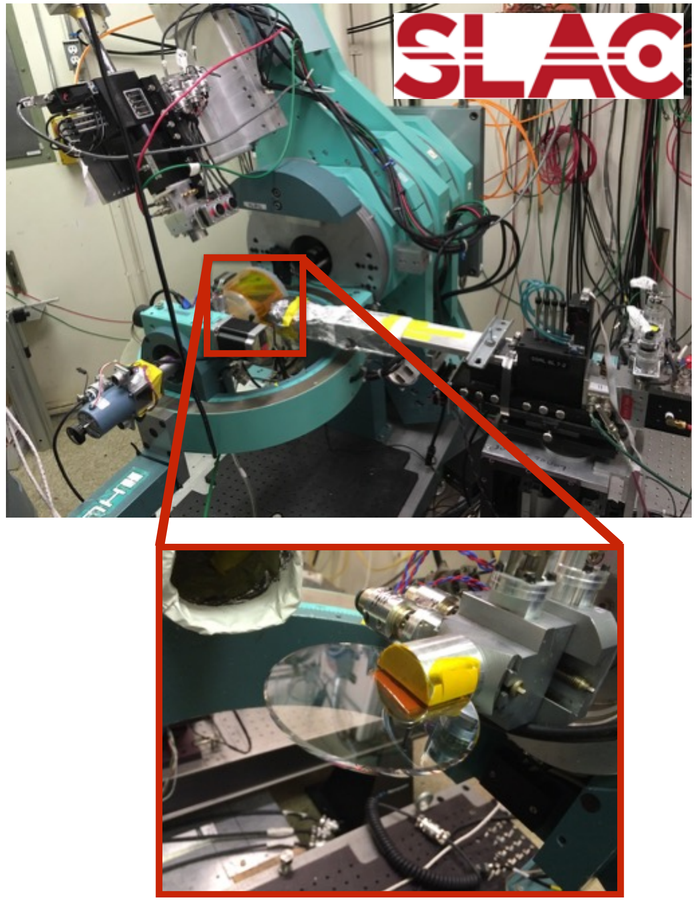
[R Bassiri et al, Acta Mat., **3**, 036103 (2015)]

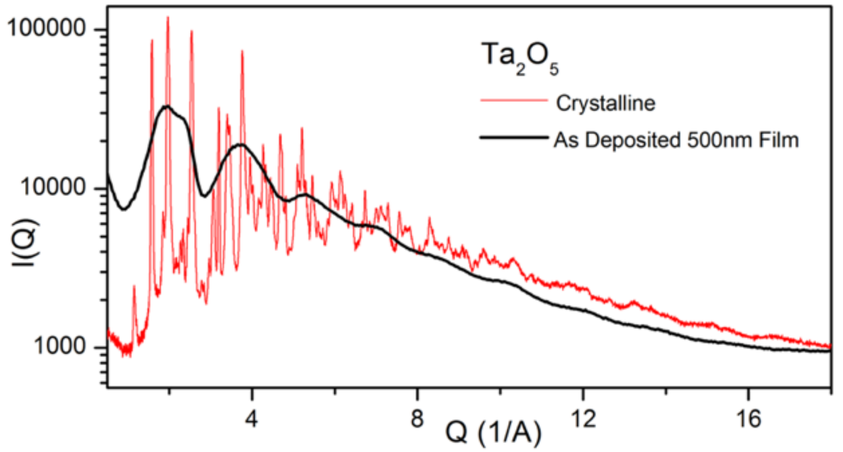


- Vibrational modes of primary structural units :
  - Zr dopant suggested to make structure more flexible
  - Experimental results underway - at least as good as Ti:Ta_2O_5
  - Si and Mg suggest to make sample more rigid - potentially reducing RT loss

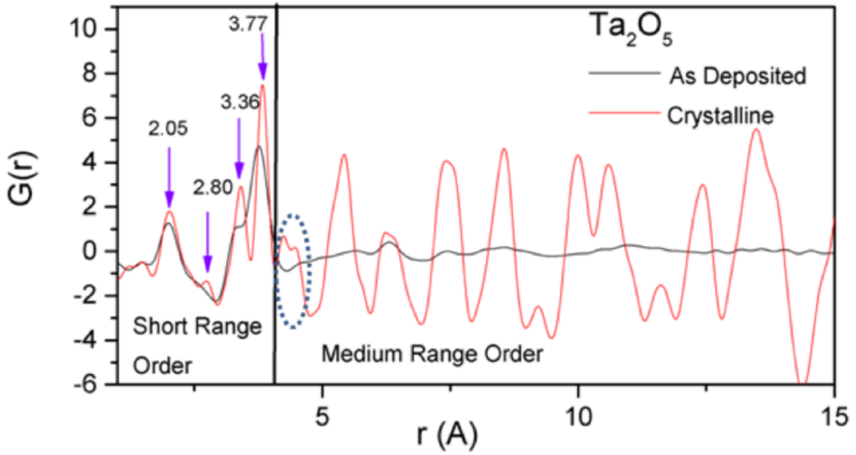
Measurement techniques:

GI-XPDF: Grazing Incidence X-ray Pair Distribution Function





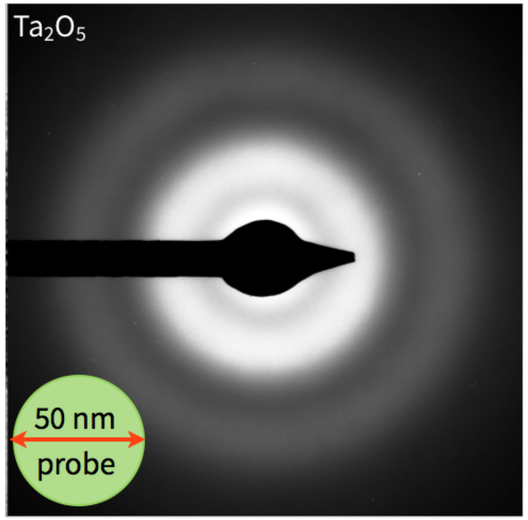
$$G(r) = 4\int_0^\infty \varphi(q)sin(qr)dq$$

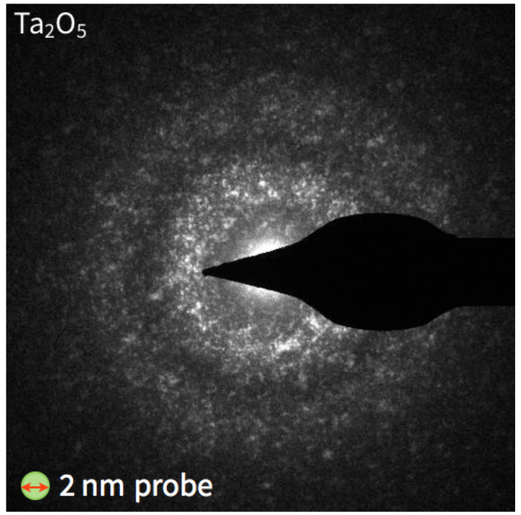


[B Shyam et al, under review]

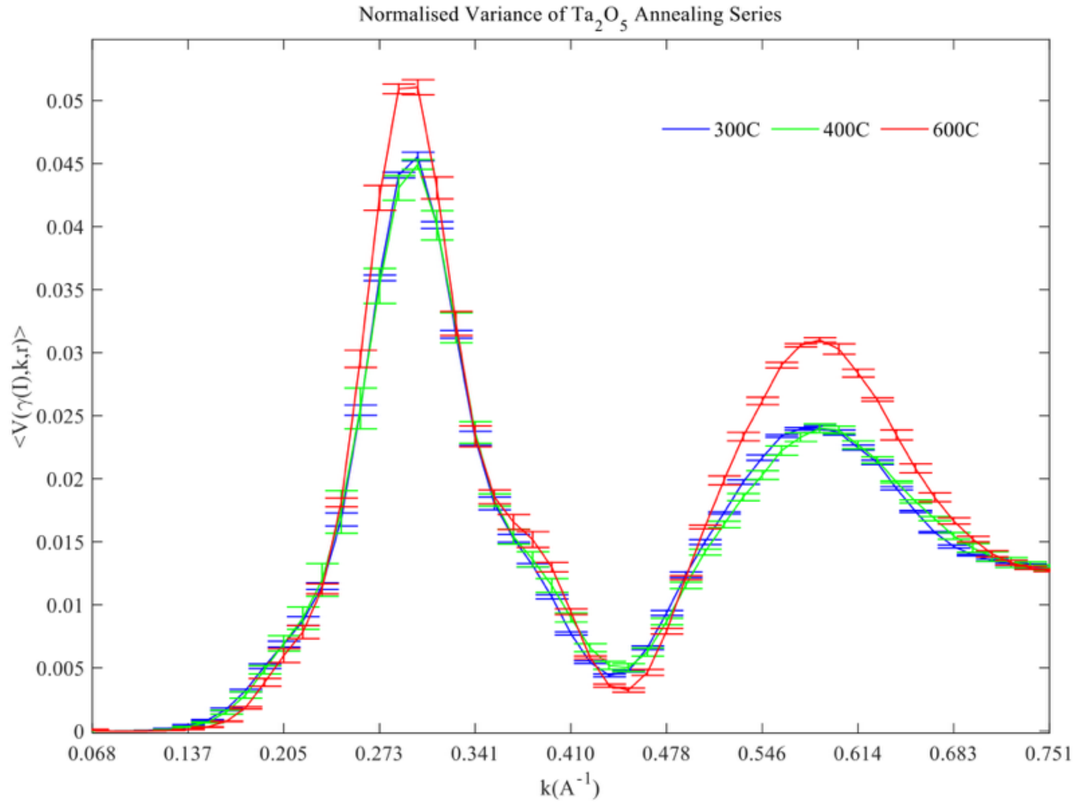
Measurement techniques:

FEM: Fluctuation Electron Microscopy



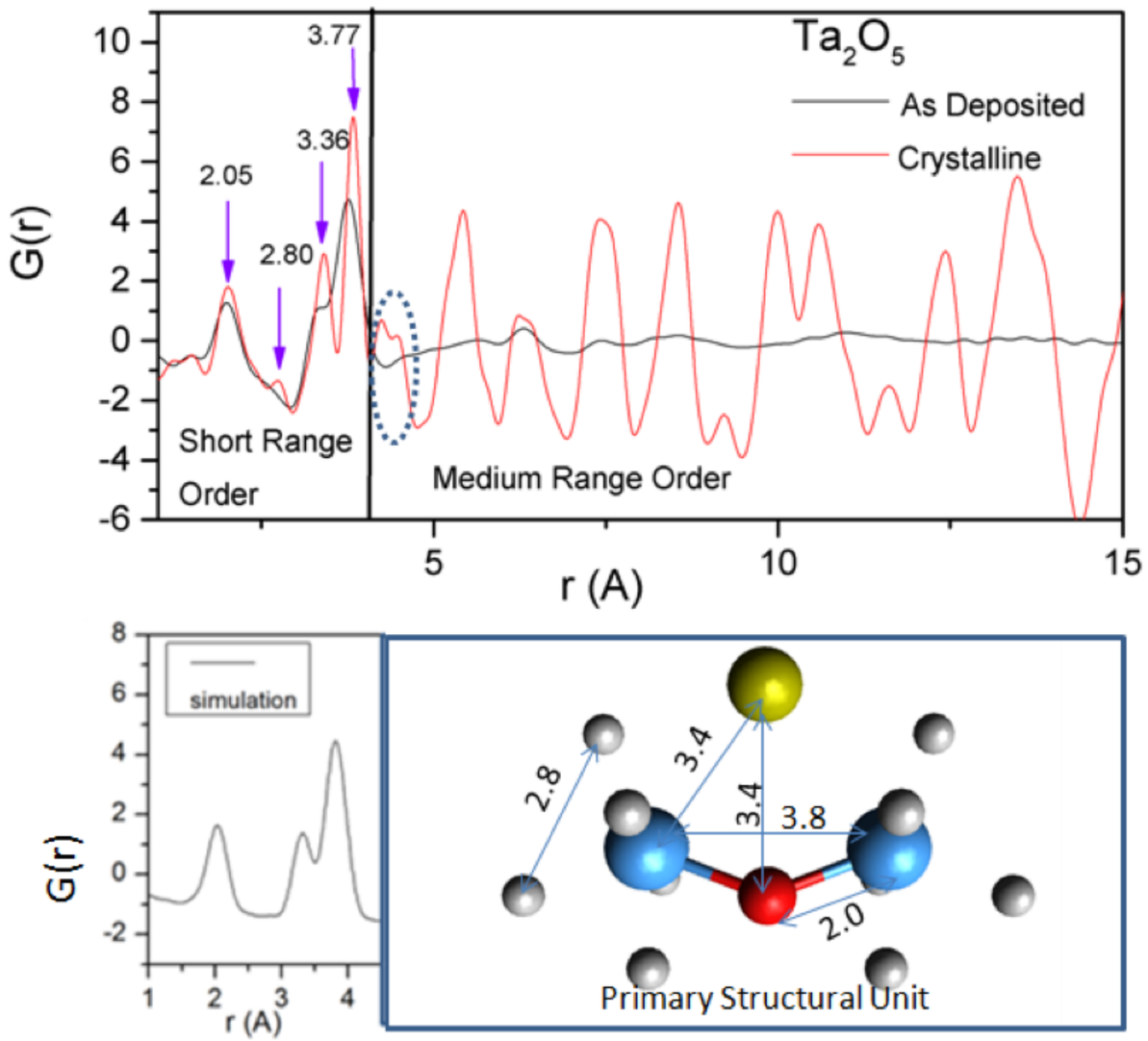


$$V(k,Q) = \frac{\langle I^2(\mathbf{r},k,Q)\rangle^2}{\langle I(\mathbf{r},k,Q)\rangle} - 1$$



[M. Hart et. al., J. Non-Cryst. Solids, **438** 10 - 17 (2016)]

Tantala: GI:XPDF

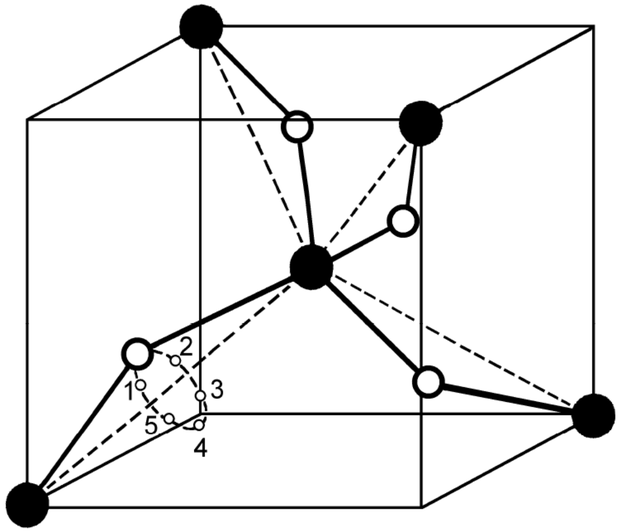


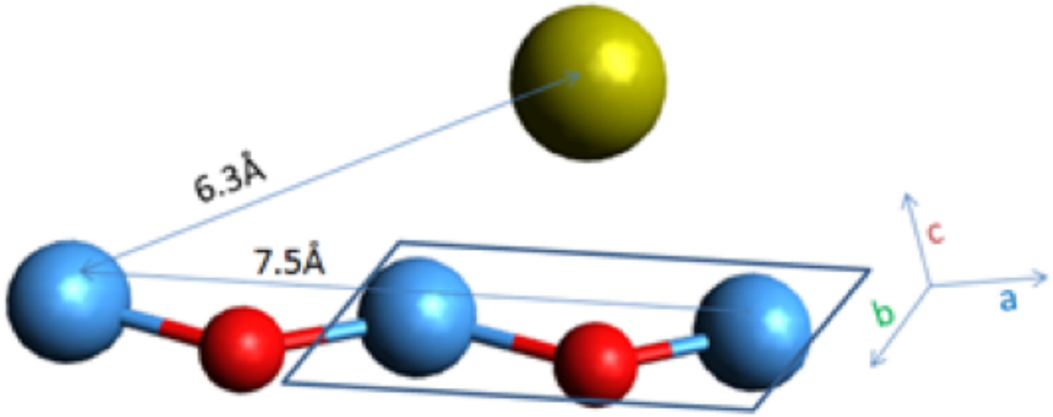
[B Shyam et al, under review]

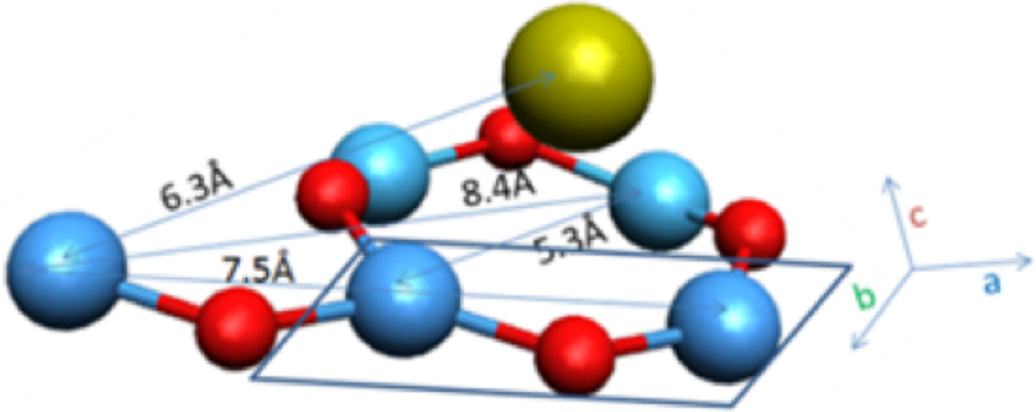
Tantala: GI:XPDF

- Modeling medium range order:
  - Extend primary structural unit
  - Suggests existence of rings similar to SiO_2 structure

- **MRO important to understanding loss mechanisms**

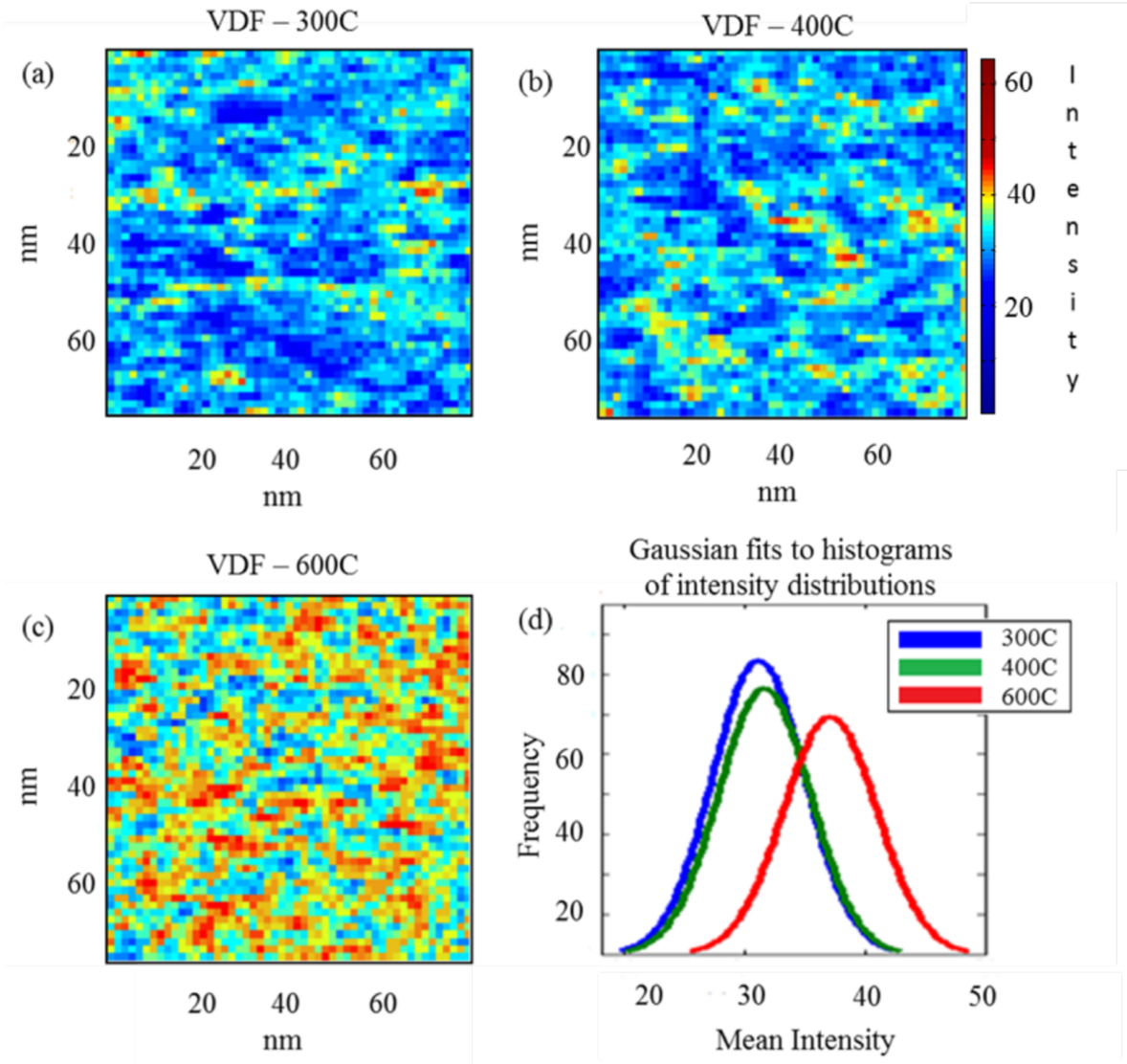






[B Shyam et al, under review]

Tantala: FEM



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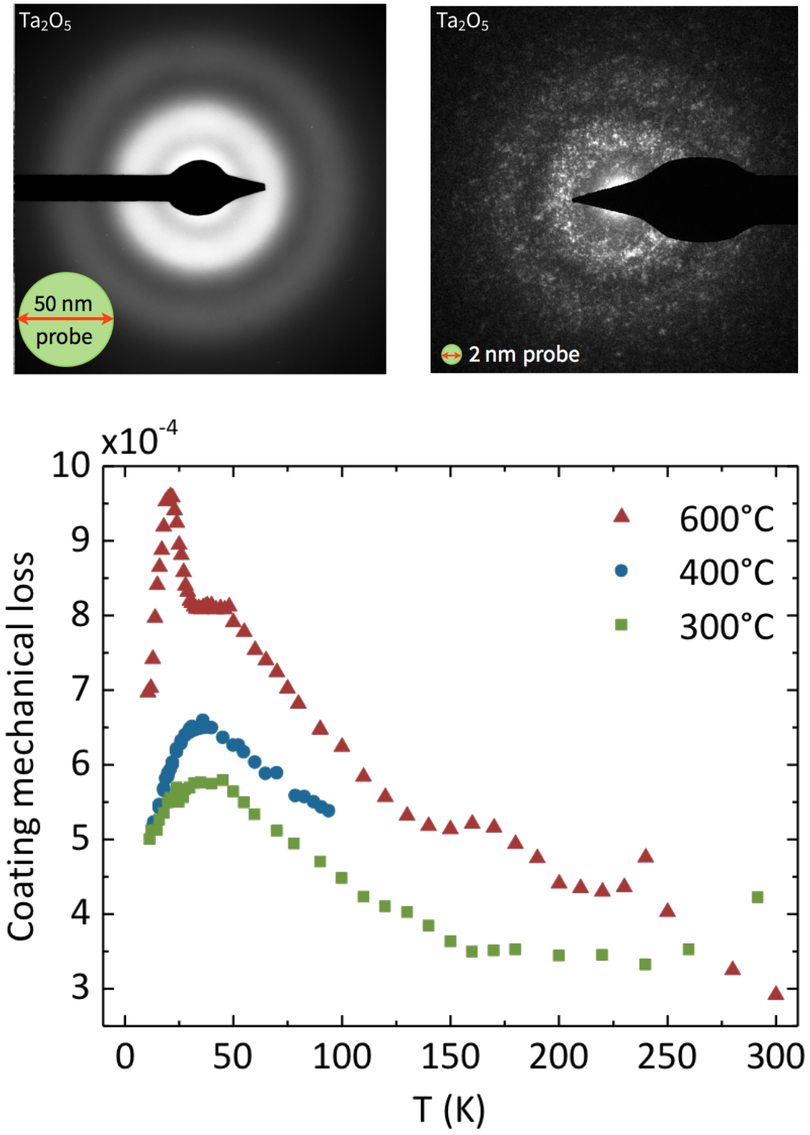

[I W Martin et al, Class. Quant. Grav. **27** 225020, 2010]

Where to next?

- Near term:
  - Medium range order in theoretical studies vs. experiment
  - Work with Hai Ping Cheng at U Florida to incorporate MRO to loss modeling

- Medium term:
  - Combine experimental to data to better constrain models
  - Test materials which could have lower loss from predictions (Mg, Si doped tantala)

- **Ultimate aim: develop a predictive tool for lower thermal noise coatings**

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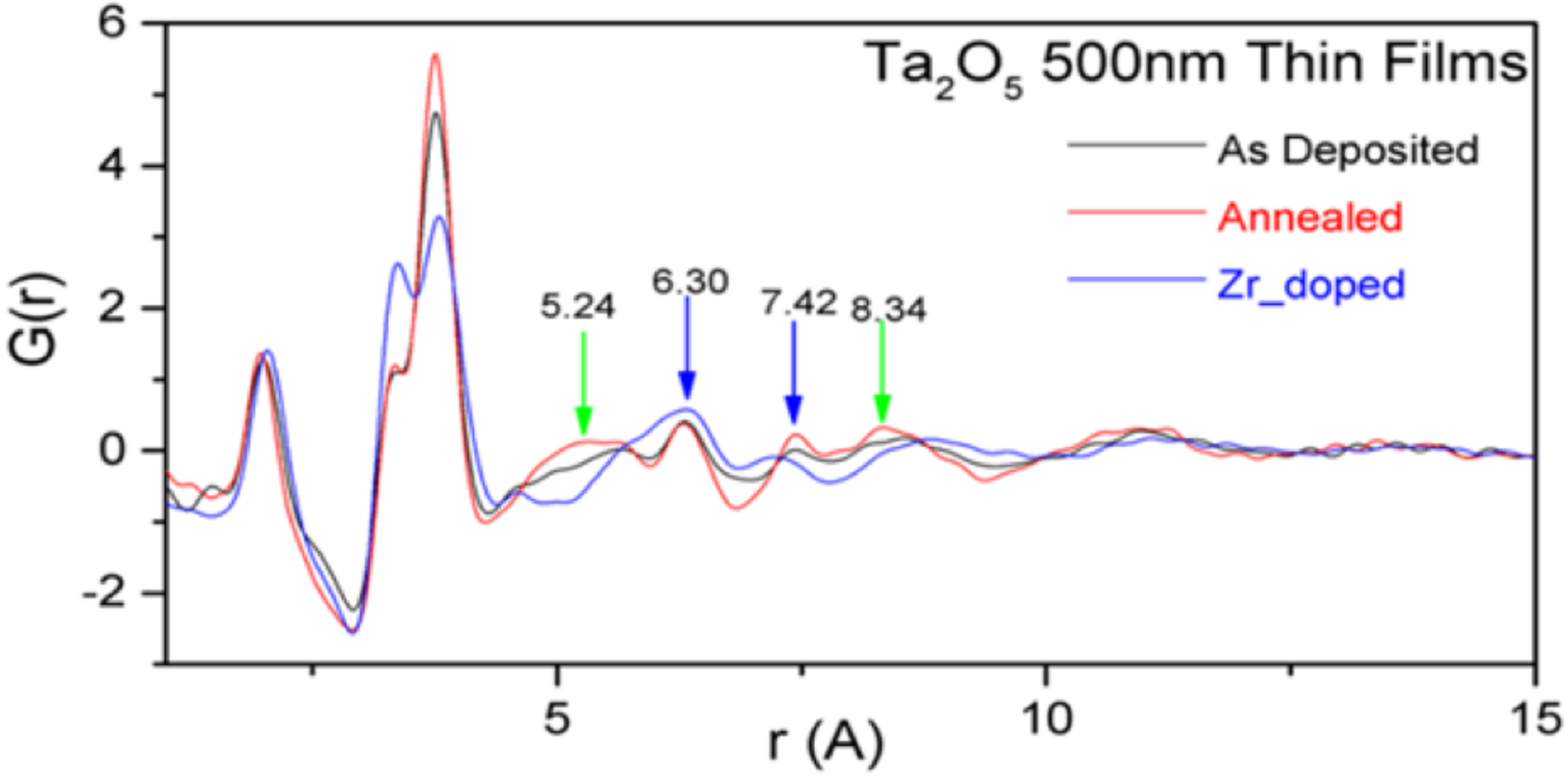
Annealed and Zirconia doped



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