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Stanford Coatings Workshop Summary

Riccardo Bassiri

6th ET Symposium | Coatings Workshop
November 20th, 2014


Stanford
University
Coatings Workshop
Friday, August 29
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Stanford University
Coatings Workshop
Friday, August 29
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Hobart & William Smith Colleges
Charting
LVC Coating
University of Glasgow
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SUPA
On b
Substrate-Transferred
Crystalline Coatings
Garrett D. Cole
Crystalline Mirror Solutions Gm
Faculty of Physics, University of
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Stanford University
Coatings Workshop
Friday, August 29
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Crystal
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A. C. Lin[1], R. Bassiri[1]
K. Haughian[2], J. Hough[2],
R. K. Rout
1. LIG
2. SUPA, School
Coatings Workshop
Friday, August 29
Atomic Structu
Noise Sources In
Crystalline Coatings
Matt Abernathy, Steve Penn, Gregg Harry
2014 Fall LVC Meeting,
Stanford
LIGO-G1401060
LIGO-G1401060
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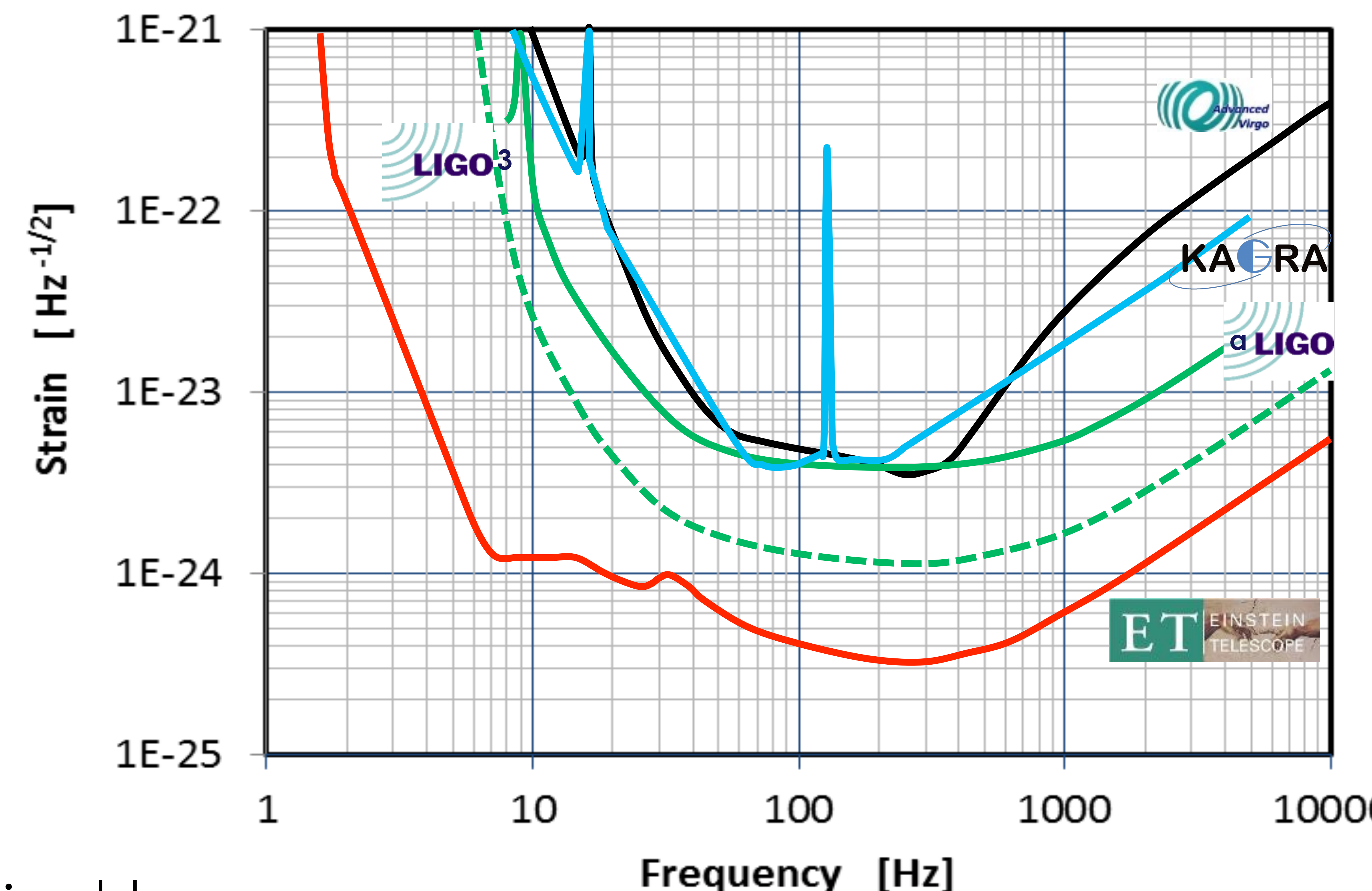
tinyurl.com/StanfordCW

Introduction

- **Reducing coating thermal noise is important for ensuring the success of future detectors**
- Coating technologies:
  - Amorphous
  - Crystalline



- Thermal noise related to mechanical loss:

temperature, coating thickness

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

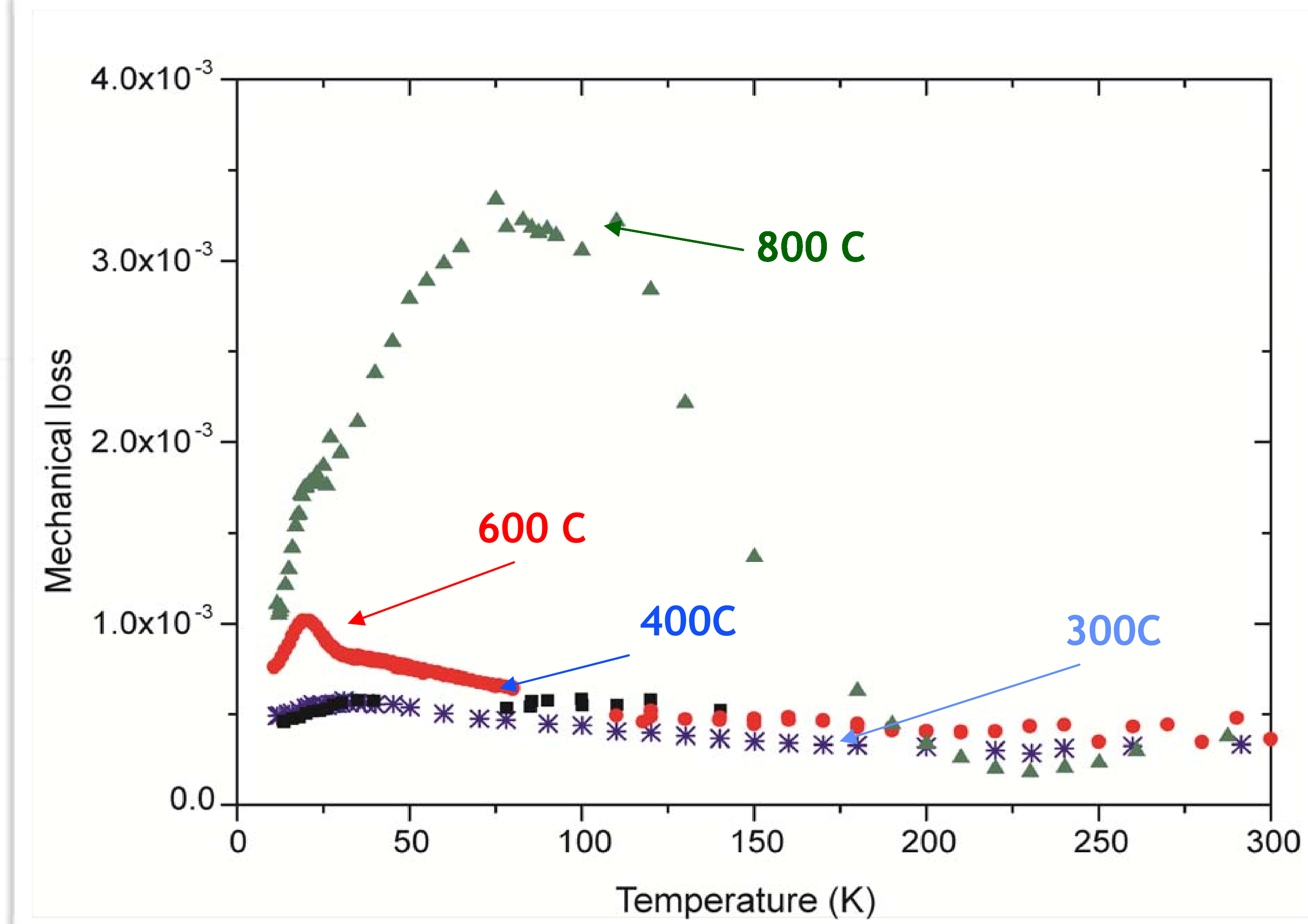
laser beam radius, coating mechanical loss

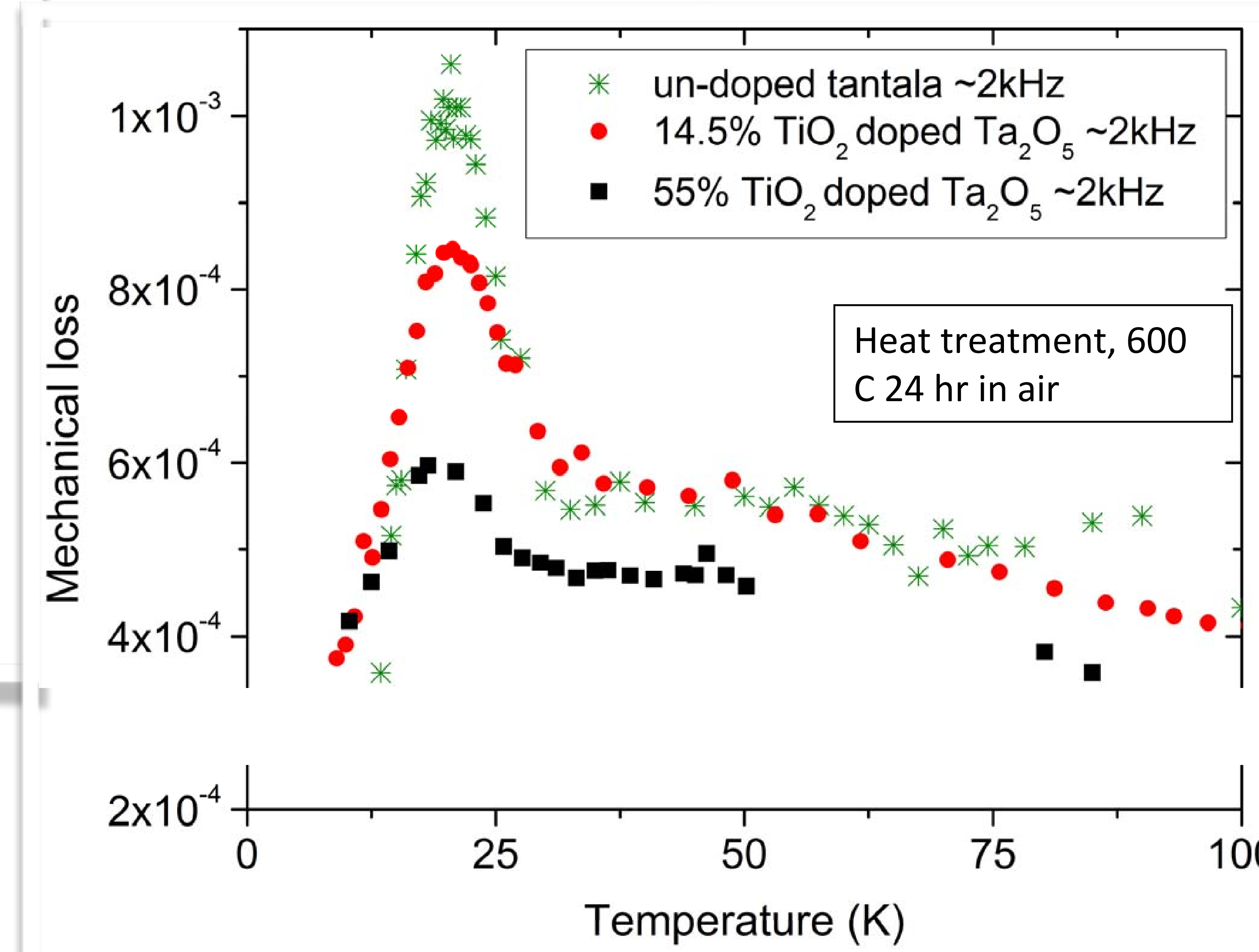
Summary

"Amorphous coatings" *Iain Martin*

- Doping and heat-treatment show some promise for reducing mechanical loss at room temperature
- Nano-layering also a very interesting option

- Optimsation of heat-treatment and doping of tantala coatings could potentially give cryogenic loss equivalent to room temperature loss
- aSi and SiNx coatings show potential for factors of 10 or more reduction in loss at cryogenic temperatures.

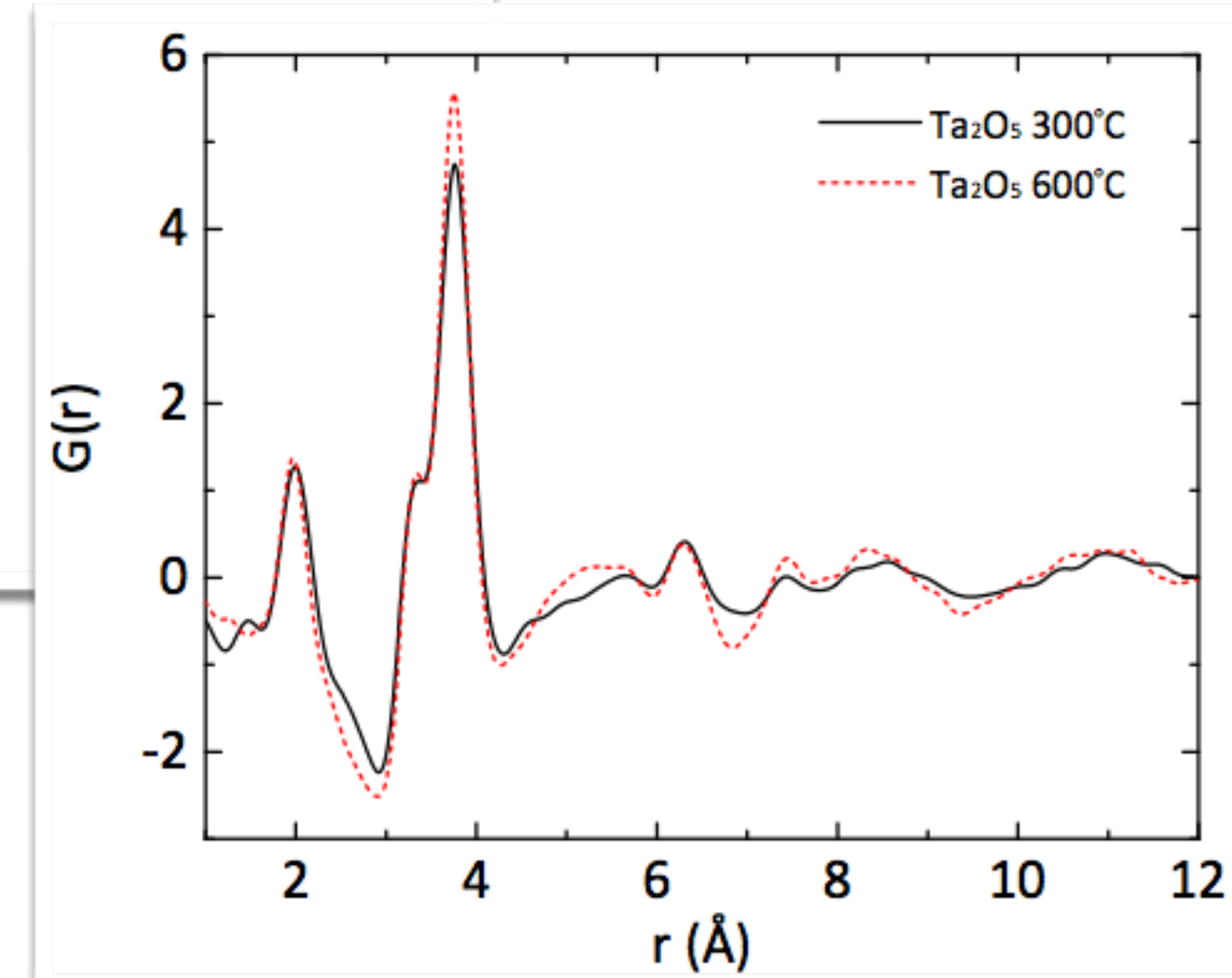




Summary

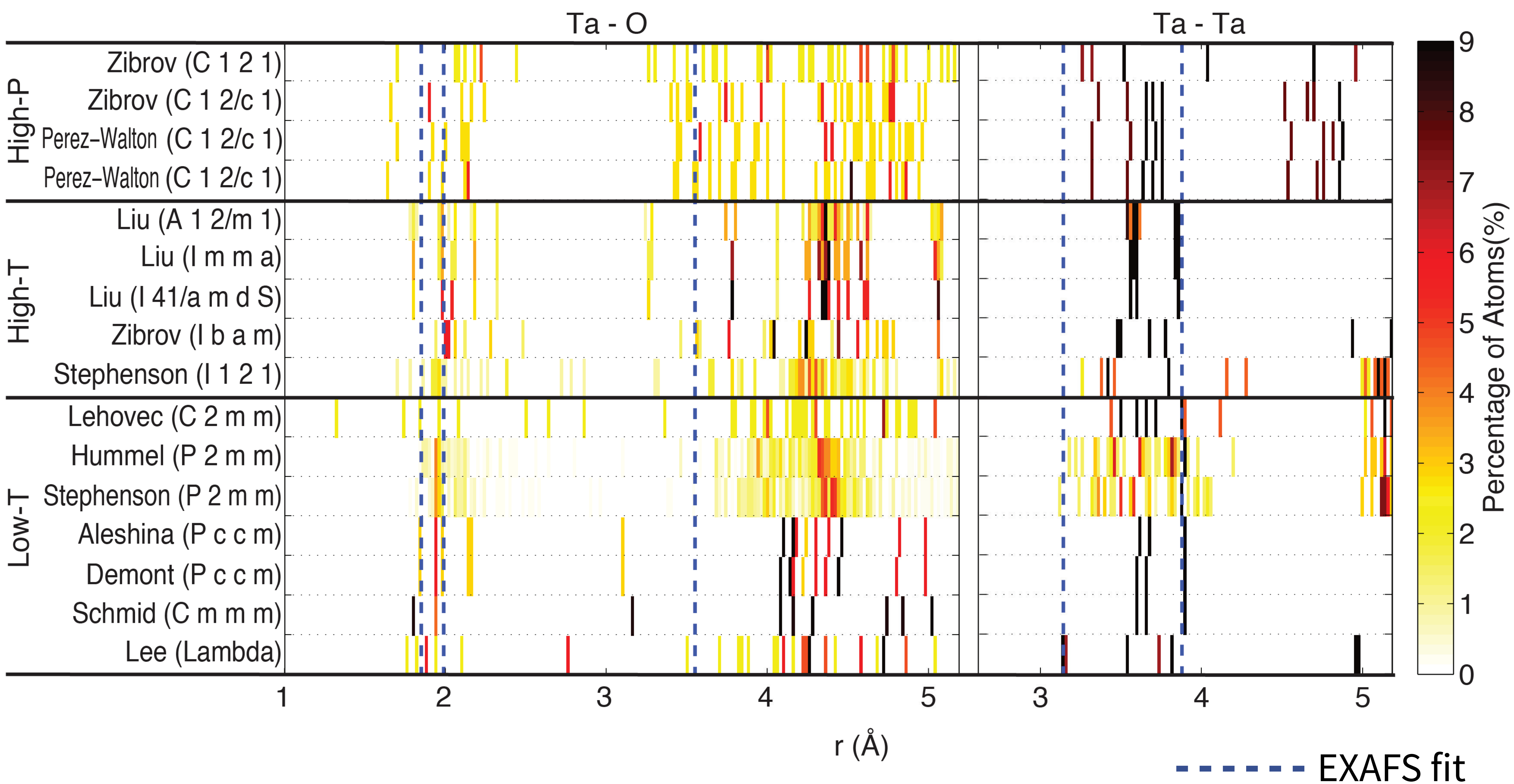
"Atomic structure overview"

- Targeted approach: coating atomic structure vs. mechanical loss
- Tantala coating atomic structure
  - Both heat-treatment and Ti-doping show larger differences in the atomic structure beyond the first nearest neighbor
  - Possible further correlation to mechanical loss
- Results will target studies to probe mechanical loss mechanisms
- Atomic structure investigations provide:
  - Capability for directed design
  - **Key route to understanding and mitigating mechanical loss, to lower coating thermal noise in amorphous coatings**



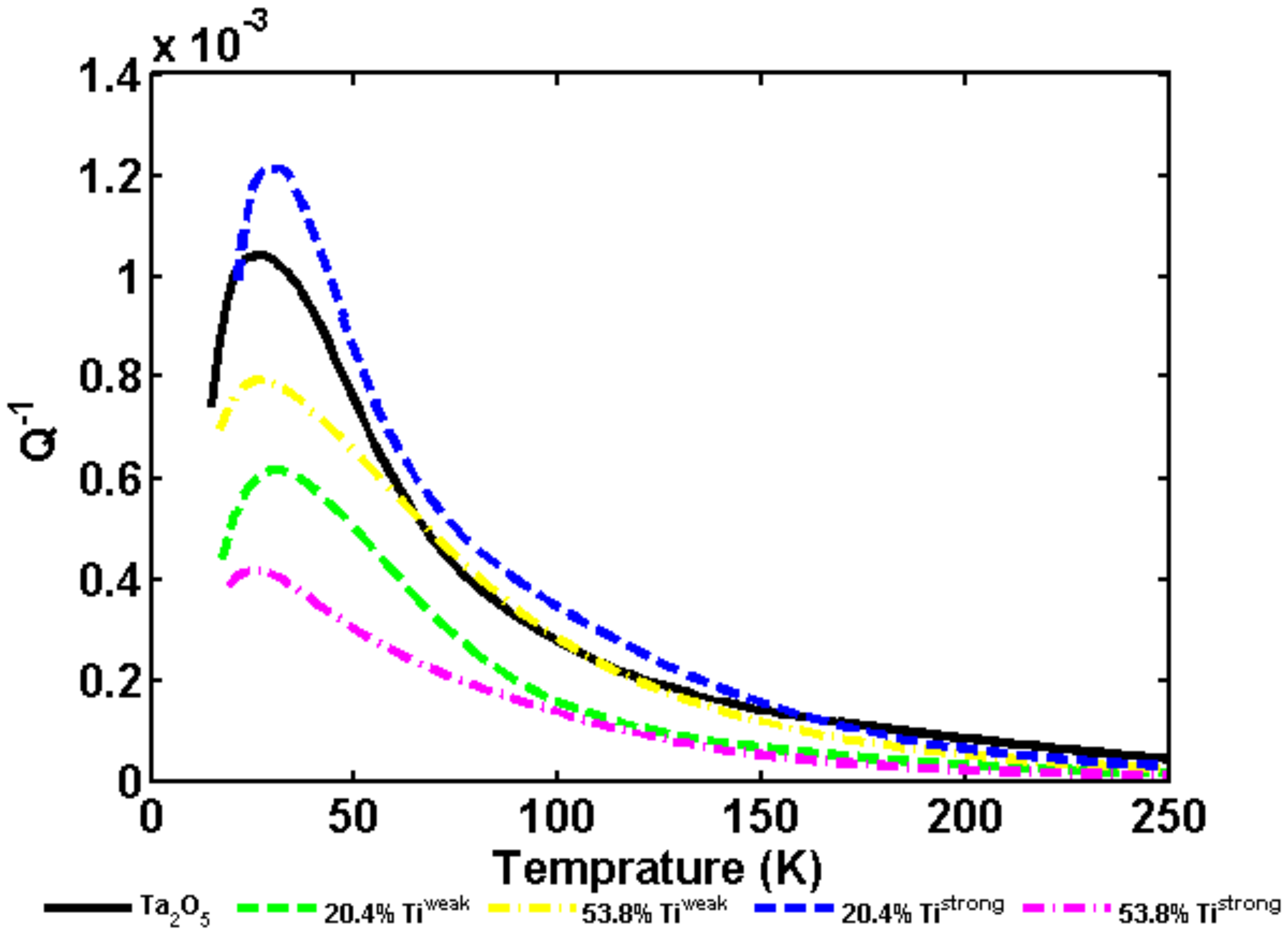
Summary

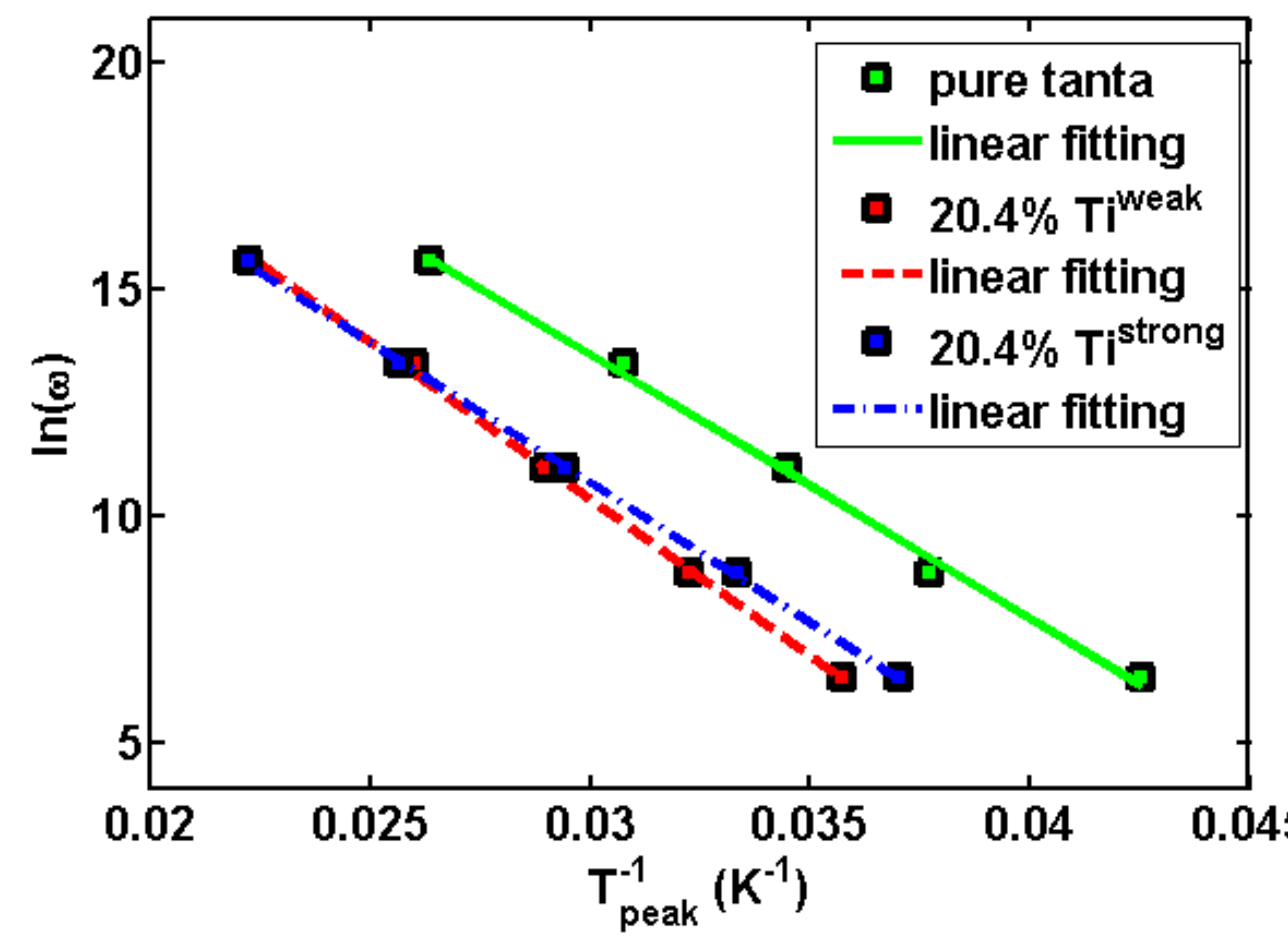
Atomic structure update: EXAFS tantala fitting LIGO-P1400192

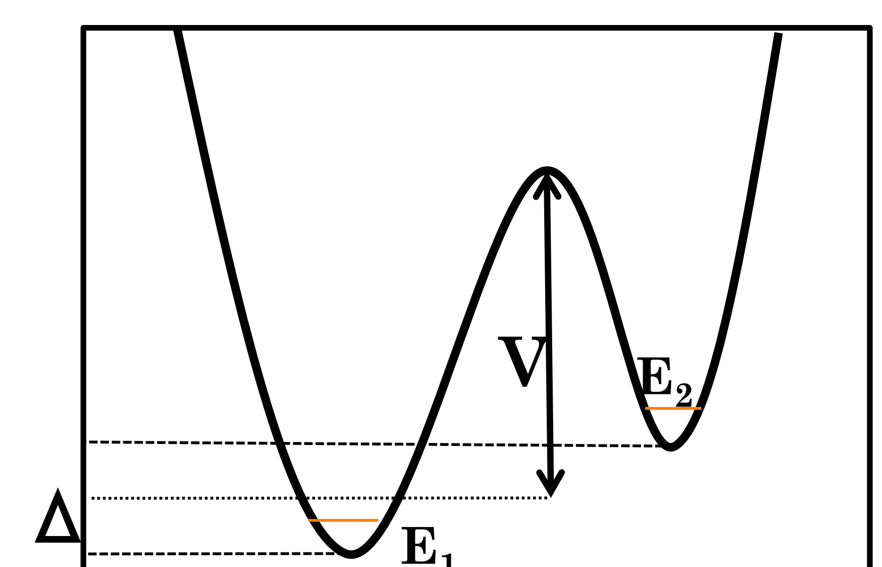


Summary

Atomic structure update: Cheng et al (more on link)





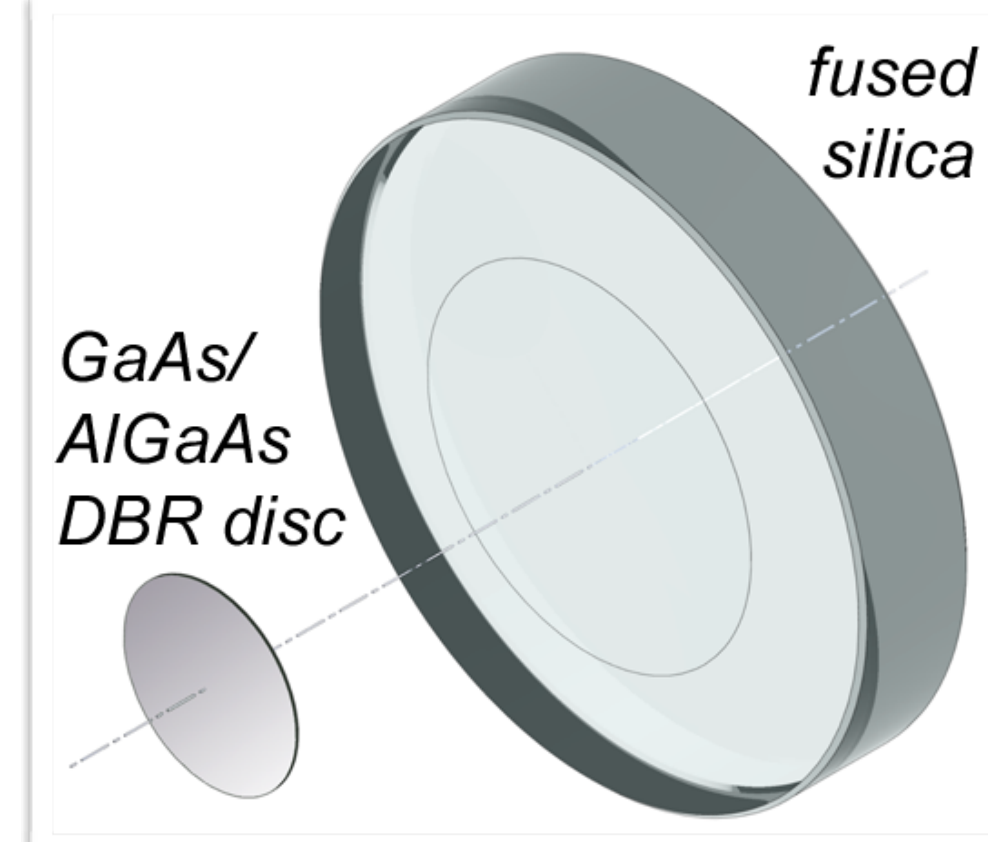


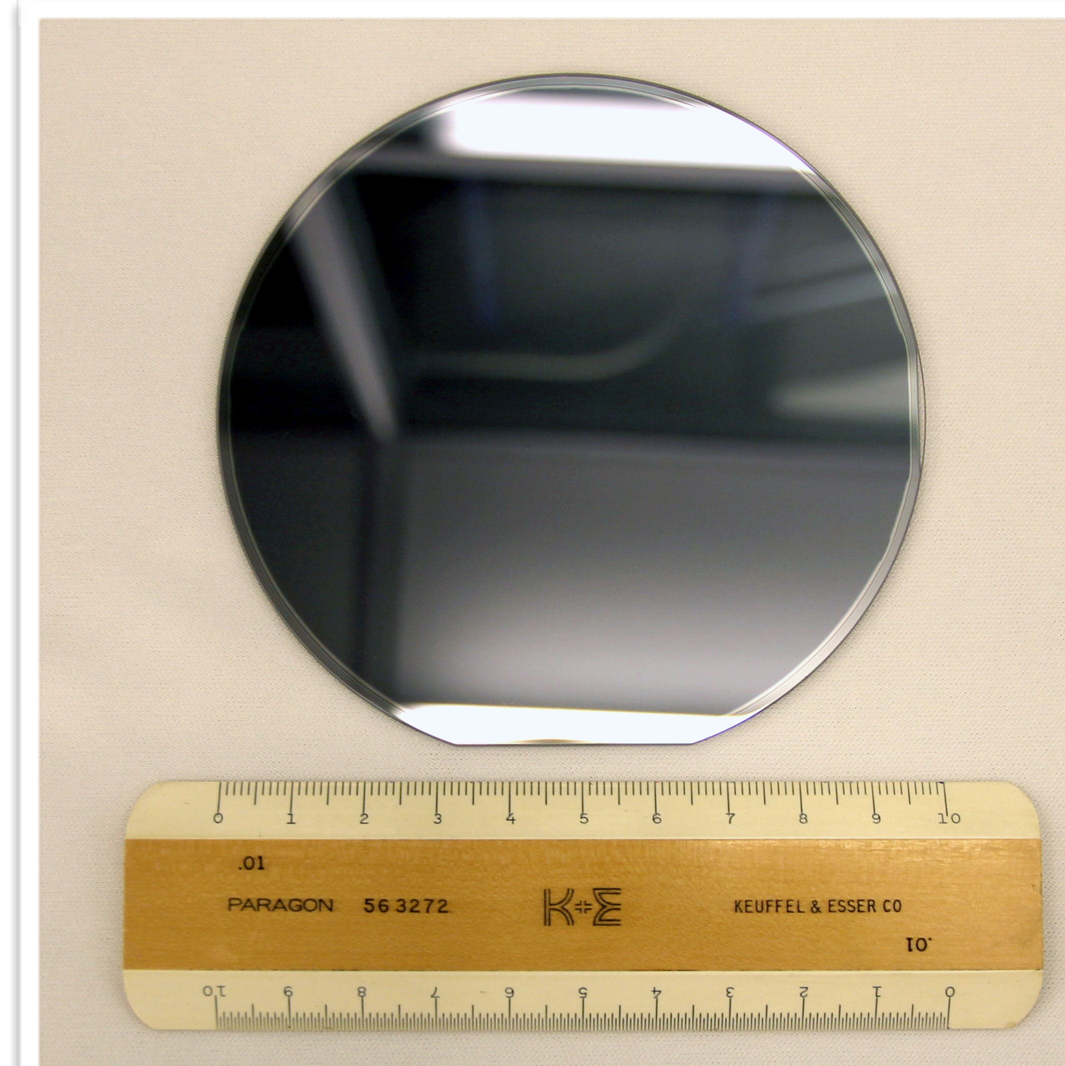
Summary

"Substrate-transferred crystalline coatings" *Garrett Cole*

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

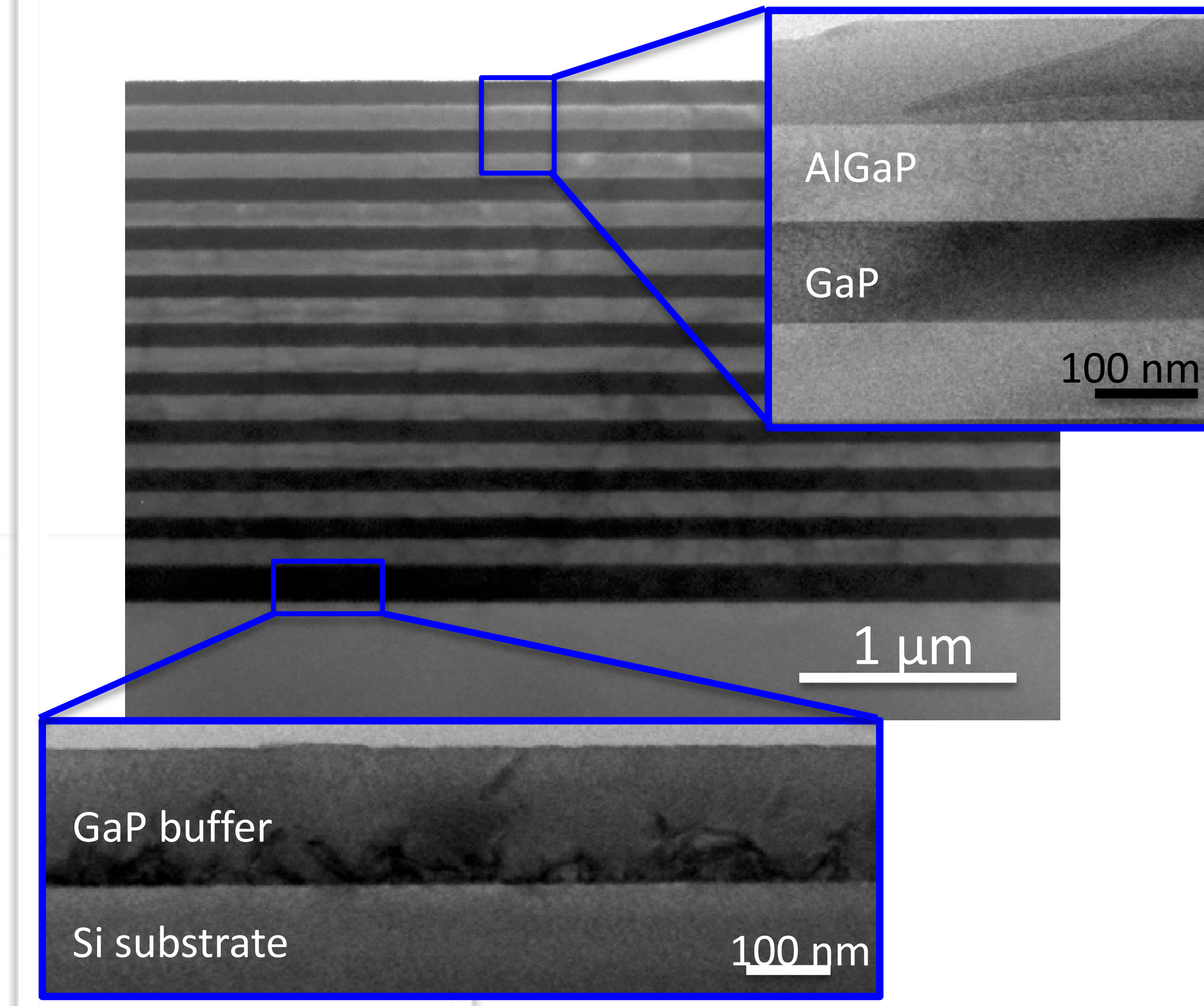
- Damping reduction of 10-100× compared with IBS films
  - IBS-deposited Ta_2O_5/SiO_2: typical Q ~3000 ($\varphi_{IBS} \approx 2\text{-}4\times10^{-4}$)
  - AlGaAs room temperature Q-value: ~4×10^4 ($\varphi_{RT} \approx 2.5\times10^{-5}$)
  - AlGaAs cryogenic performance: Q >1×10^5 ($\varphi_{min} \approx 4.5\times10^{-6}$)
- Minimal scattering loss and optical absorption
  - RMS surface roughness of 1.3 Å RMS (~2 ppm at 1064 nm)
  - absorption (probe limited) of 4.8 ppm (0.15 cm^{-1}) at 1064 nm
- Reflectivity >>99.99% measured for 40.5 layer pairs
  - highest measured finesse of ~2×10^5 at 1064 nm





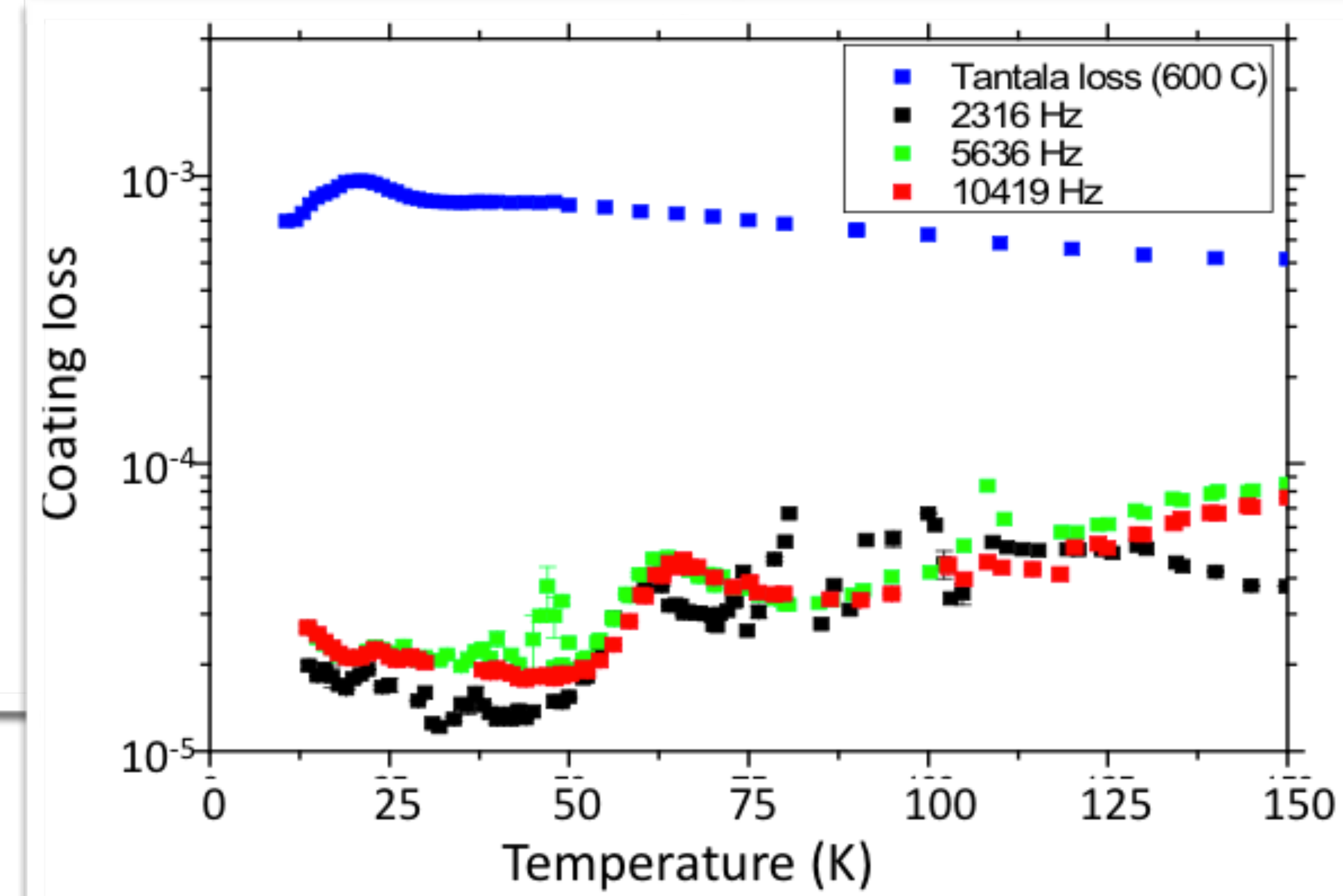
Summary

“Crystalline coatings: GaP/AlGaP” *Martin Fejer*



Future Development

- No further growth program at Stanford
  - working with Glasgow and UWS to continue development
- Elastic loss already adequate
- Origin and control of optical absorption next step
- Scatter loss and homogeneity characterization



Summary

"Noise sources in crystalline coatings" *Matthew Abernathy*

The Threat Matrix

		Mechanical				Electrical		Thermal			Optical		ElectroOptic		MagnetoOptic		Nonlinear Optic				Other			
		Elasticity	Mech Loss	Piezoelectric	Birefringence	Resistance	Electrostriction	Thermal Exp.	PhotoThermal	PyroElectric	Dispersion	Absorption	Pockels	Kerr	Faraday	M-O Kerr	2nd Harm Gen	Para. Down.	Optical Kerr	DC Rect?	2 Photon Abs	FerroMag	ParaMag	FerroElec.
		$C_{\alpha\beta}$	$\phi_{\alpha\beta}$	$\left(\frac{\partial D_\alpha}{\partial \sigma_\beta}\right)_E$	$\frac{dn}{ds}$	R	$\frac{ds_{ij}}{dP_k dP_l}$	α_L	$\frac{dn}{dT}$	$\frac{dE}{dT}$	$\frac{dn}{d\lambda}$	Im (ϵ)	$\frac{dn}{dE}$	$\frac{dn}{dE^2}$	$\frac{dn}{dH}$	$\frac{dn}{dH}$	$\lambda \to \lambda/2$	$\lambda \to 2\lambda$	$\frac{dn}{dI}$	$\frac{dE}{dI}$				
Mechanical	Elasticity									0			T1400404											
	Mech Loss									0			T1400404											
	Piezoelectric									0			T1400404											
	Birefringence									0			T1400404											
Electr.	Resistance									0														
	Electrostrict.									0			T1400404											
Thermal	Thermal Exp.									0			T1400404											
	PhotoThermal									0			T1400404											
	PyroElectric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Optical	Dispersion									0			T1400404											
	Absorption									0														
ElecOpt	Pockels	T1400404	T1400404	T1400404	T1400404		T1400404	T1400404	T1400404	0	T1400404													
	Kerr									0														
Mag-Opt	Faraday									0														
	M-O Kerr									0														
Nonlinear Optics	2nd Harmonic									0														
	Para. Down.									0														
	Optical Kerr									0														
	DC Rect?									0														
Other	2 Photon Abs									0														
	FerroMag									0														
	ParaMag									0														
	FerroElec.									0														

Outcomes

2017 Milestone

Conservative

- Bigger optics with aLIGO coatings
  - Up to 60 cm diameter
  - Work with vendors and suspension group
- Optimize titania doped tantala coatings

Less conservative

- Change titania doping concentration in tantala coatings
- Change dopant in tantala coatings, or new oxide mixture

Optimistic

- Nano-layer coatings (titania/silica)
  - Challenges: optical quality, scalability

Outcomes

2025 Milestone

Crystalline coatings

- Materials
  - AlGaAs, 20 cm in 5 years, 30 cm in 10 years, may be possible
  - AlGaP, Stanford working with Glasgow and UWS to continue development
- Challenges
  - absorption (5 ppm in AlGaAs), scatter, scalability, uniformity
- Development
  - Ultimately LIGO needs own MBE system for AlGaAs and AlGaP
  - UWS and LMA are gearing up to be able to do AlGaP

Outcomes

2025 Milestone

Amorphous coatings

- **Materials**
  - Change dopant in tantala coatings, or new oxide mixture
  - a-Silicon: low mechanical loss, need to reduce absorption
  - Fluorides: CaF, YtF
  - Nitrides: SiN and SiO_xN_y
- **Development**
  - Atomic structure studies aim to direct new coating material investigations
  - Manufacturing scalability 1” to 12” (MLD: about 1 year)

Conclusions

- **Reducing coating thermal noise is important for ensuring the success of future detectors**
- **Ongoing research and development:**
  - Amorphous coatings
    - New material combinations, manufacturing conditions to reduce mechanical loss
    - Atomic structure measurements aim to direct new coating material investigations
  - Crystalline coatings
    - Encouraging mechanical loss, potential for 2025 milestone
    - Challenges remain in development for large scale optics
- **Research focussed on developing coatings for major milestones**
  - 2017 (LIGO A+), 2025 (LIGO Voyager)

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