Initial X-ray absorption spectroscopy measurements in LIGO mirror coatings*

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Talk Outline

- Motivation
- Experiment
- Data & Analysis
- Results
- Summary & Future Work

Objective:

Obtain physical correlations between chemical impurities and/or dopants (Ti, Cr, Fe, Co, etc.) and optical absorption characteristics of materials under consideration for use as test masses and **optical coatings** in advanced LIGO.

SUBR Measurements Program

X-ray Fluorescence (XRF)	CAMD, SSRL, ALS
Extended X-ray absorption fine structure (EXAFS)	CAMD
X-ray absorption near edge spectroscopy (XANES)	CAMD, SSRL
Neutron Activation Analysis (INAA)	NIST
Prompt Gamma Neutron Activation Analysis (PGNAA)	NIST
Neutron Depth Profiling (NDP)	NIST
Electron Spin Resonance (ESR)	NIST

Coatings Samples

Four (4) samples received June 23, 2005.

Sample #1

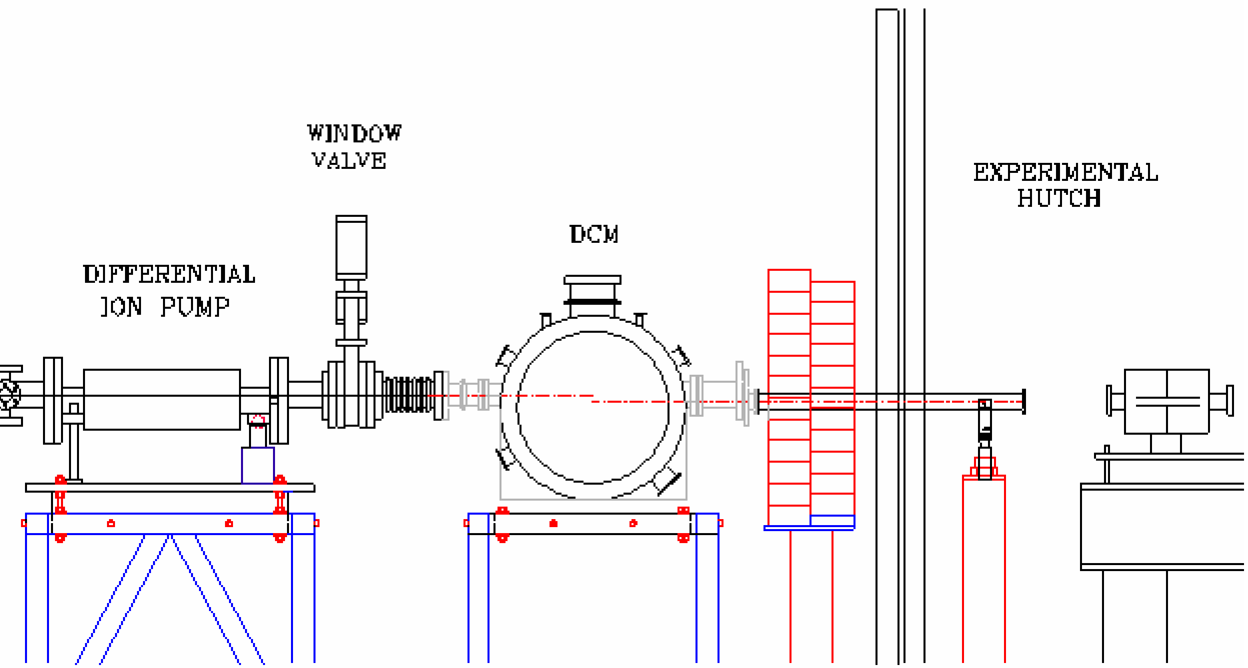
300°C MLD

Sample #3

Sample #4

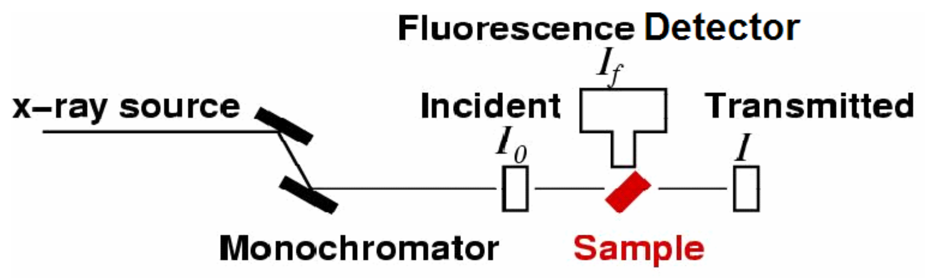
Samples are ~9.5 mm SiO_2 wedges with coatings.

Double Crystal Monchromator Beamline



CAMD Experimental Hall

13 element Ge photon detector array



LIGO

X-ray fluorescence (XRF) Theory

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$$N_{X\text{-}rays} = N_{atoms} \int \sigma(E)\phi(E)dE \cdot [\omega(\exp(-\Sigma_i \mu_i \delta x_i))\varepsilon \Delta T] \qquad (1)$$

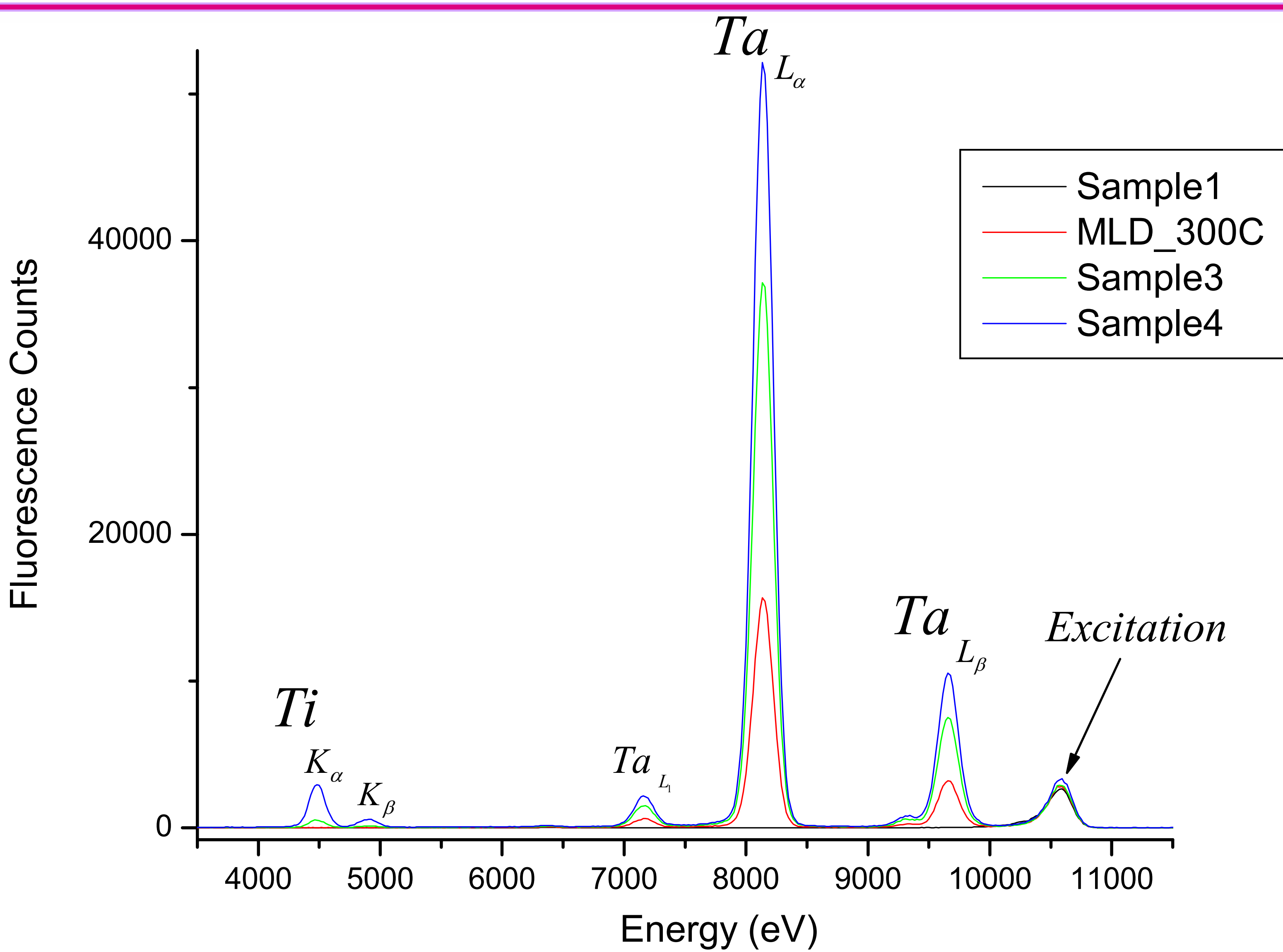
For a monoenergetic beam of energy, E_o ,

$$\boxed{N_{X\text{-}rays} = N_{atoms}\, \sigma(E_o)\phi(E_o)\omega(\exp(-\Sigma_i \mu_i \delta x_i))\varepsilon \Delta T} \qquad (2)$$

where

$N_{X\text{-}rays}$	=	number of background–subtracted X-rays	
N_{atoms}	=	number of target atoms seen by the beam	
σ	=	photoelectric cross section	(cm^2)
ω	=	fluorescence yield	
ϕ	=	flux of incident X-rays	($\#/cm^2 \cdot s$)
μ_i	=	linear attenuation coefficient(s)	(/cm)
δx_i	=	Secondary X-ray pathlength(s)	(cm)
ε	=	photopeak detection efficiency	
ΔT	=	detector live time	(s)

XRF Data taken at CAMD



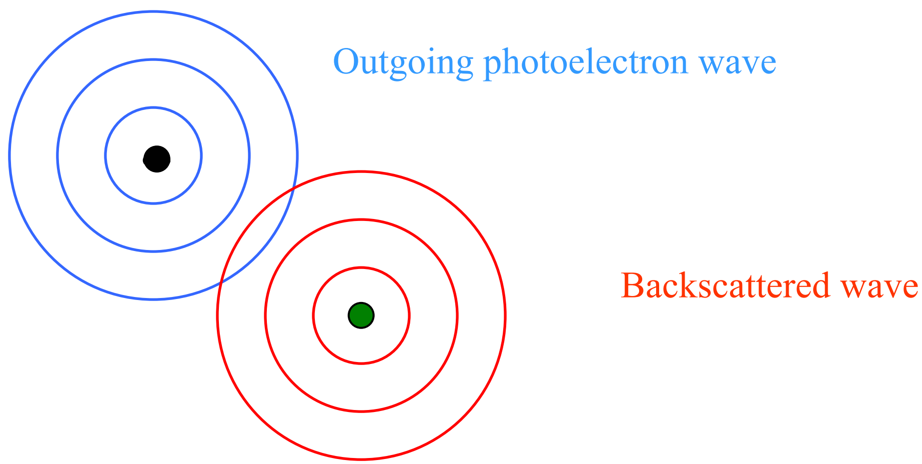
X-ray Absorption Spectroscopy

Excitation of a specific core electron with monochromatic X-ray source

Events prior to and subsequent to ejection of electron provide useful information about the system

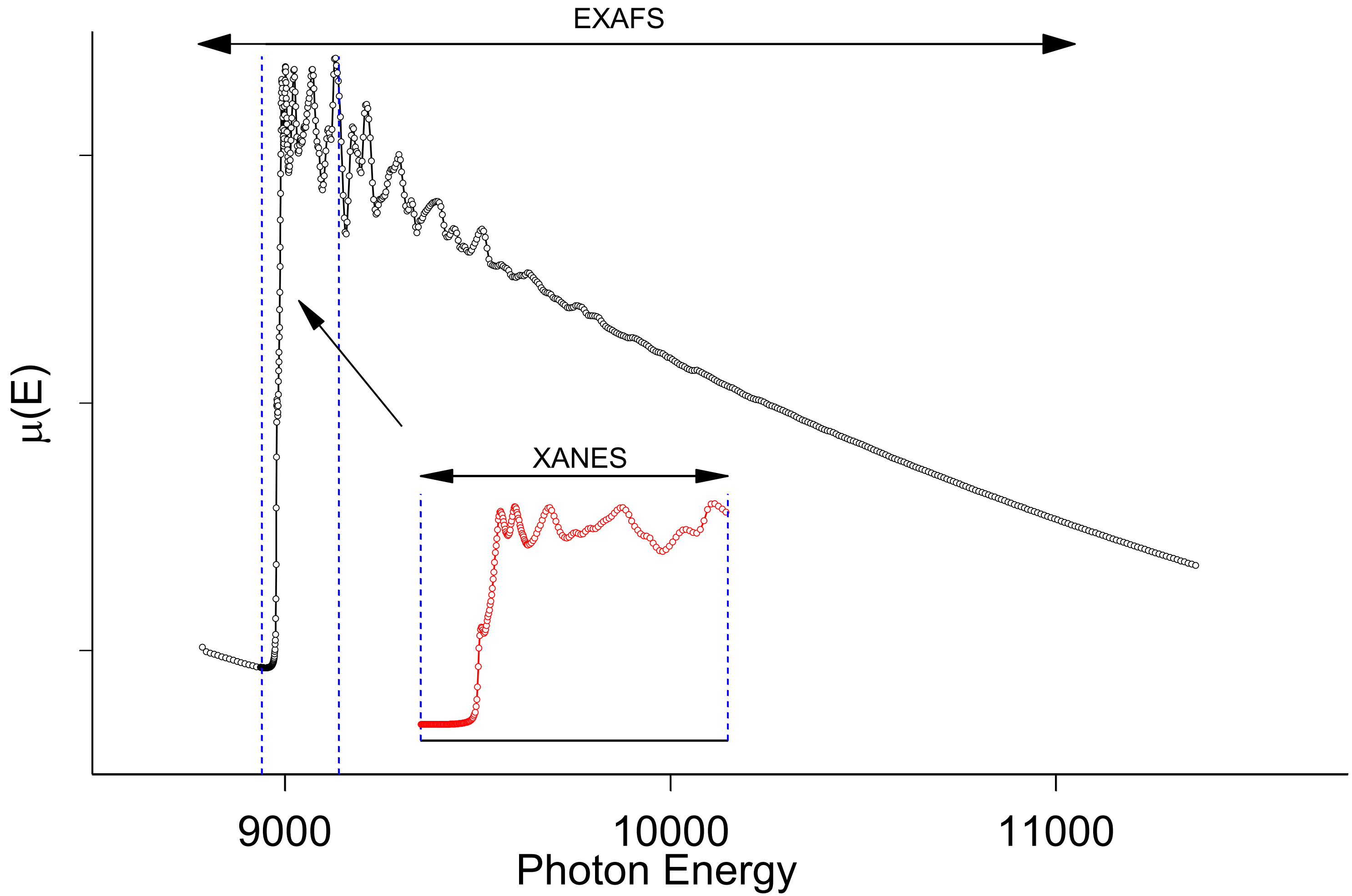
XANES	EXAFS
(X-ray Absorption Near-Edge Spectroscopy)	(Extended X-ray Absorption Fine Structure)
Information Provided	**Information Provided**
Presence or absence of specific bonds	Identity of neighbors
Oxidation state	Neighbor coordination numbers
Orientation	Interatomic distances
	Thermal or static disorder

A visual representation



- Interaction of waves from absorber and backscattering neighbor yield information on the system.

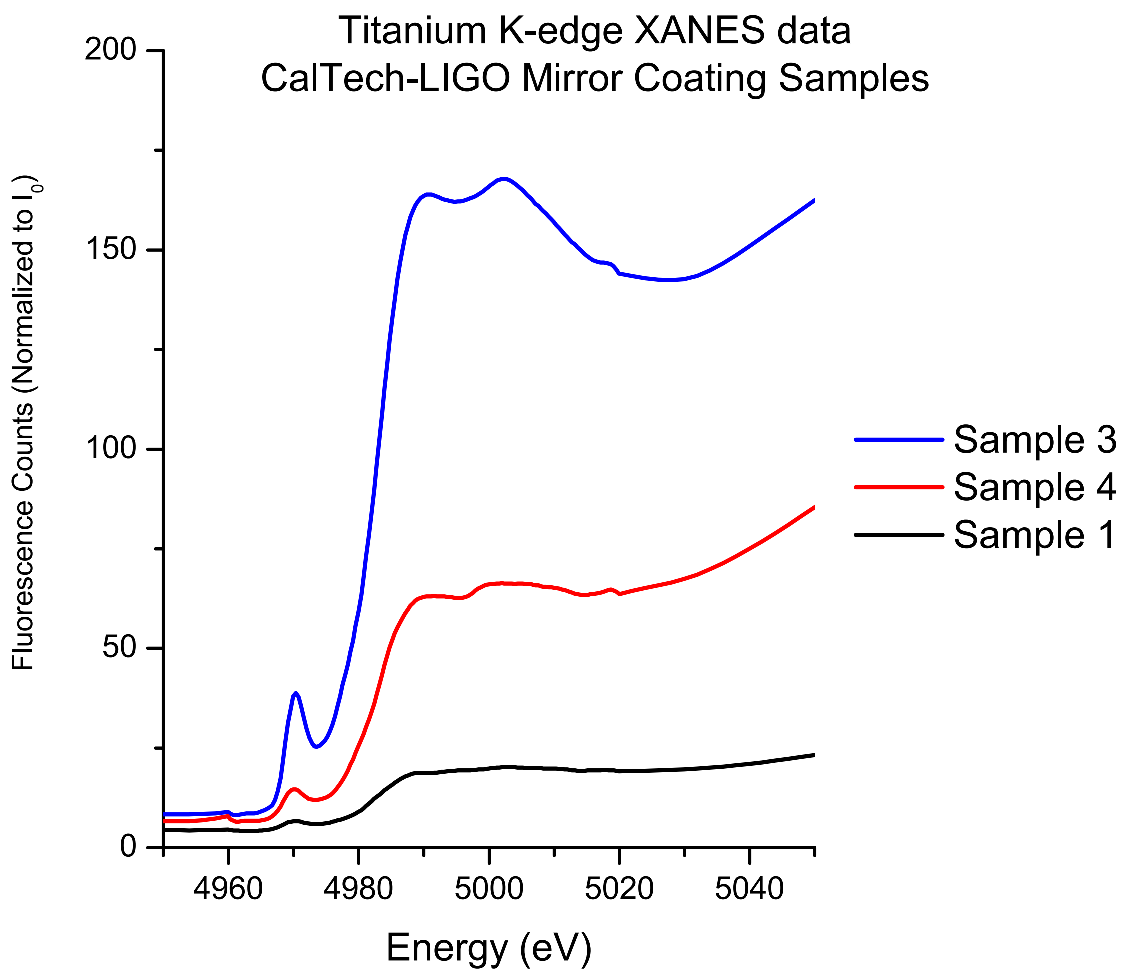
X-ray Absorption Spectrum



XANES Theory

- The near edge region is dominated by multiple-scattering of the low kinetic energy photoelectron by neighboring atoms
- Edge position is a function of oxidation state
- Coordination and molecular orbitals influence peak shapes
- Comparison with known spectra allows for ‘fingerprinting’ of samples

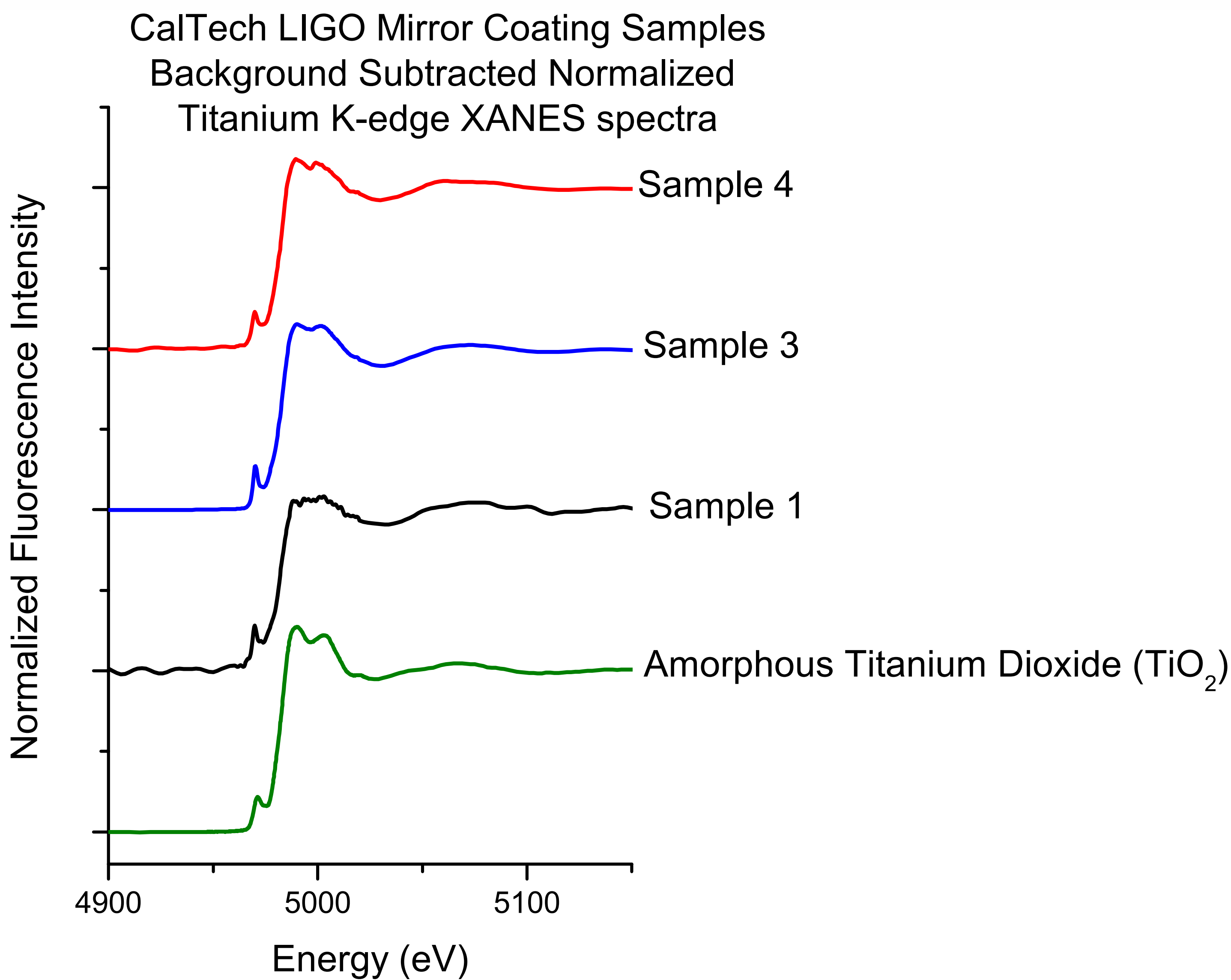
XANES Data taken at CAMD



Information gained

- The intensity of each uncorrected spectrum in the previous figure is an indicator of the amount of titanium present (fluorescence intensity is roughly proportional to # of titanium atoms present)
- The shape of the spectrum is a function of the chemical state of the titanium (titanium oxide)

Normalized XANES Data



Results

In the experiments conducted thus far:

- Clear signals for elements of primary interest (Ti and Ta) have been observed for samples 3 and 4.
- Relative concentration of titanium in samples 3 & 4 has been estimated: Ti(S4)/Ti(S3) = 6.1 $\pm$ 2.01 % (counting statistical uncertainty only).
- These initial results are encourage a long-term program of measurements.
- CAMD beamtime proposal is in preparation.
- Measurements are applicable to the investigation of other dopant/substrate systems.

Summary & Future Work

- Identified major coating components and some trace elements on surfaces.
- Titanium is deposited as an amorphous oxide.
- Future grazing incidence experiments will allow for selective examination of coating surface with reduced scatter from substrate.
- Complementary X-ray diffraction studies are planned.
- Simulations of spectra with FEFF code are ongoing.

Questions?

and/or

Discussion

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