Coating Program Status Report

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- On behalf of Coating Working Group -

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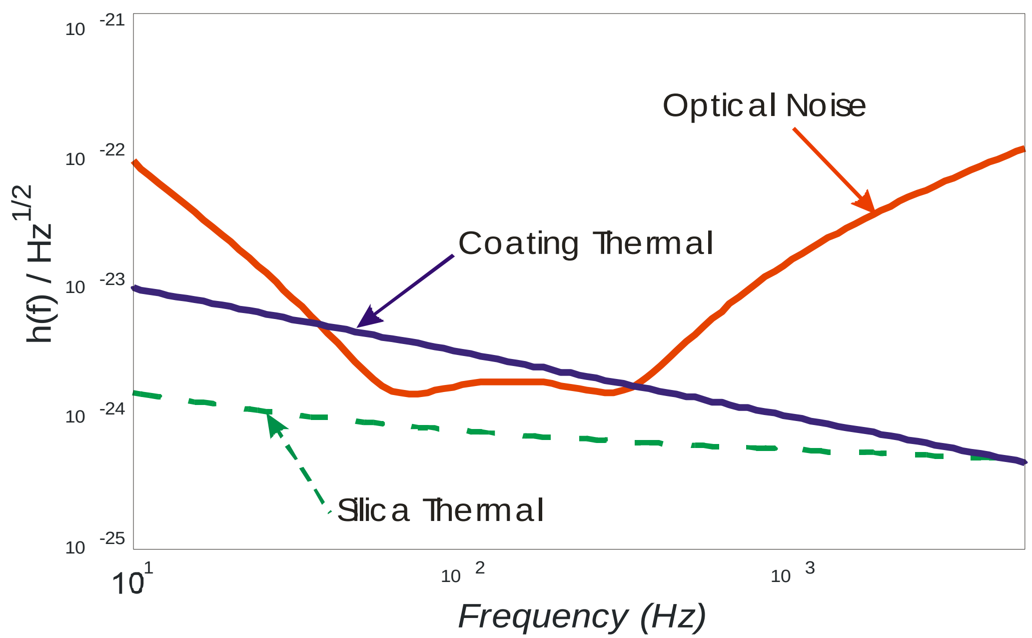
Outline

- Review of coating problems
- Review of methods
- Summary of previous results
- New results
  - Doped tantala
  - Single layers of materials
- Work in progress
- Plans for future research
- Introduction to non-periodic coating

Problems

Thermal Noise

- Initial LIGO coating too lossy
  - Loss angle $\phi = 2.7\ 10^{-4}$
  - Limits sensitivity to ~160 Mpc for BNS
- Reduce mechanical loss
  - Goal $\phi = 5\ 10^{-5}$
  - ~200 Mpc BNS range
- Need to preserve optical, thermal, other mechanical properties



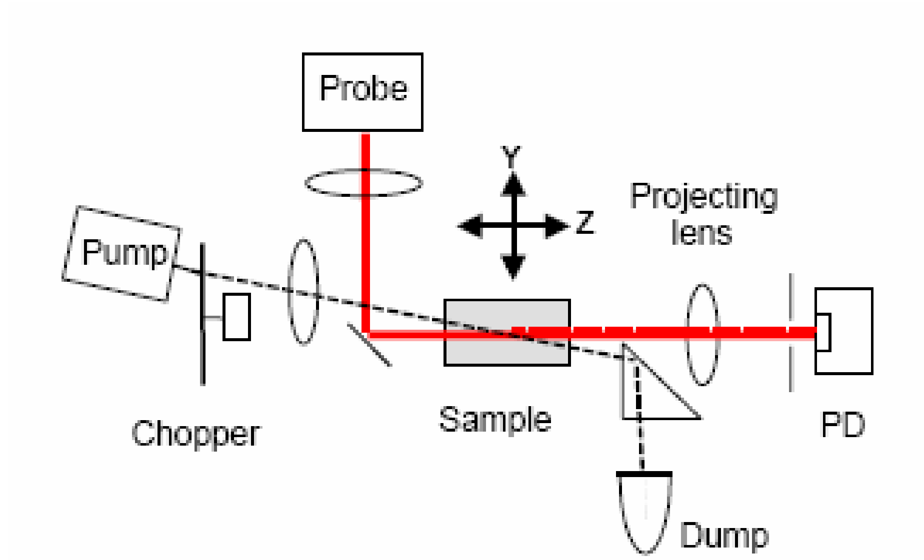
Thermal Compensation

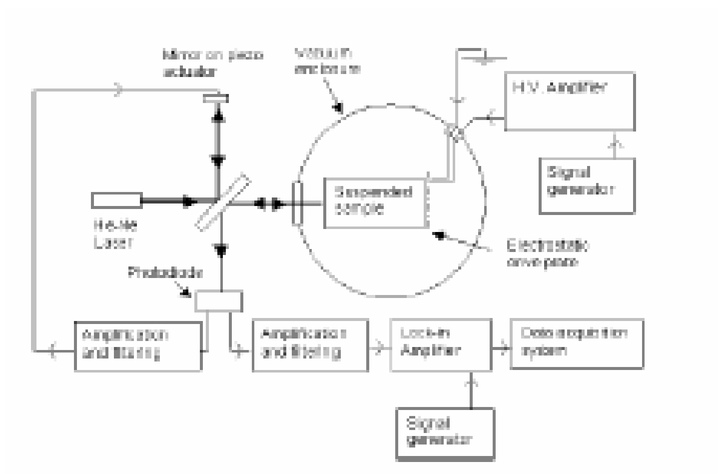
- Absorption in coating dominant source of heating
- Need to reduce absorption
  - Average homogeneous < 0.5 ppm
  - Inhomogeneous

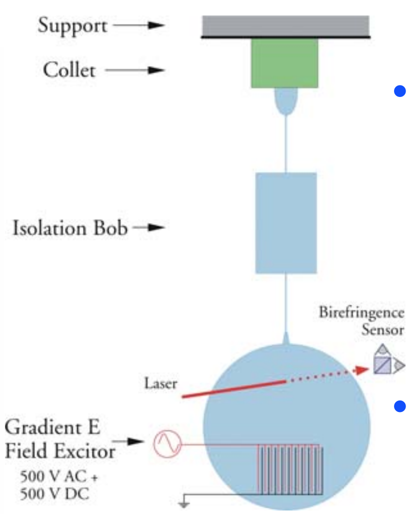
Methods

Thermal Noise

- Ringdown Q's
  - Thin and thick samples
  - Get before and after Q's
- Modeling
  - Get modal energy in coating
  - Calculate coating ϕ
- Glasgow, MIT, HWS







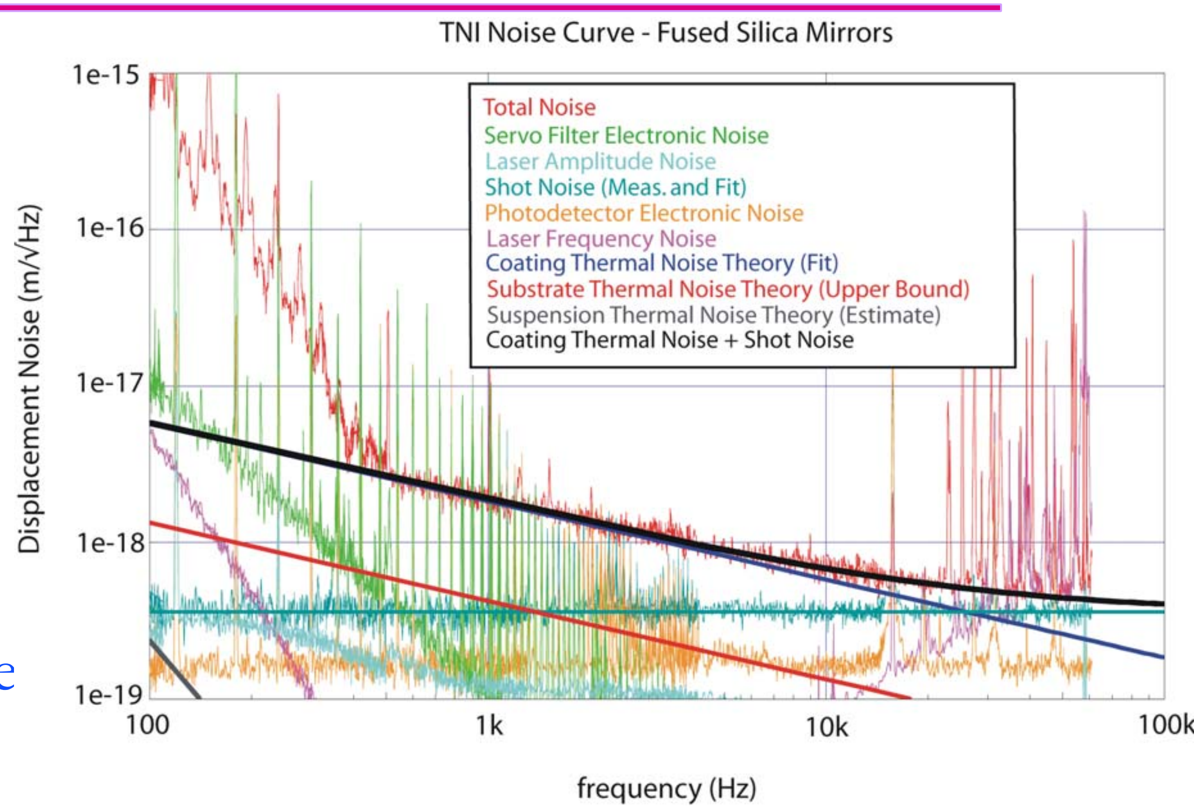
Optical Absorption

- Photothermal Common-Path Interferometry
  - Can measure sub-ppm absorption
  - Spatial resolution sub-mm
- Stanford, LMA/Virgo

Summary of Current Status

Thermal Noise

- Silica/tantala coating
  - Loss from internal friction
  - Tantala has dominant loss
  - Minor differences between vendors
- Other materials
  - Niobia similar to tantala
  - Alumina similar to silica
- Doping tantala with titania reduce mechanical loss
  - Low concentrations
- Direct measurement
  - TNI
- Theory of coating noise
  - Brownian and thermoelastic
  - Need Young's modulus



Other Properties

- Titania doping allows for at least 1 ppm absorption
- Titania doping leaves index of refraction and Young's modulus unchanged

New Results
Formula 3

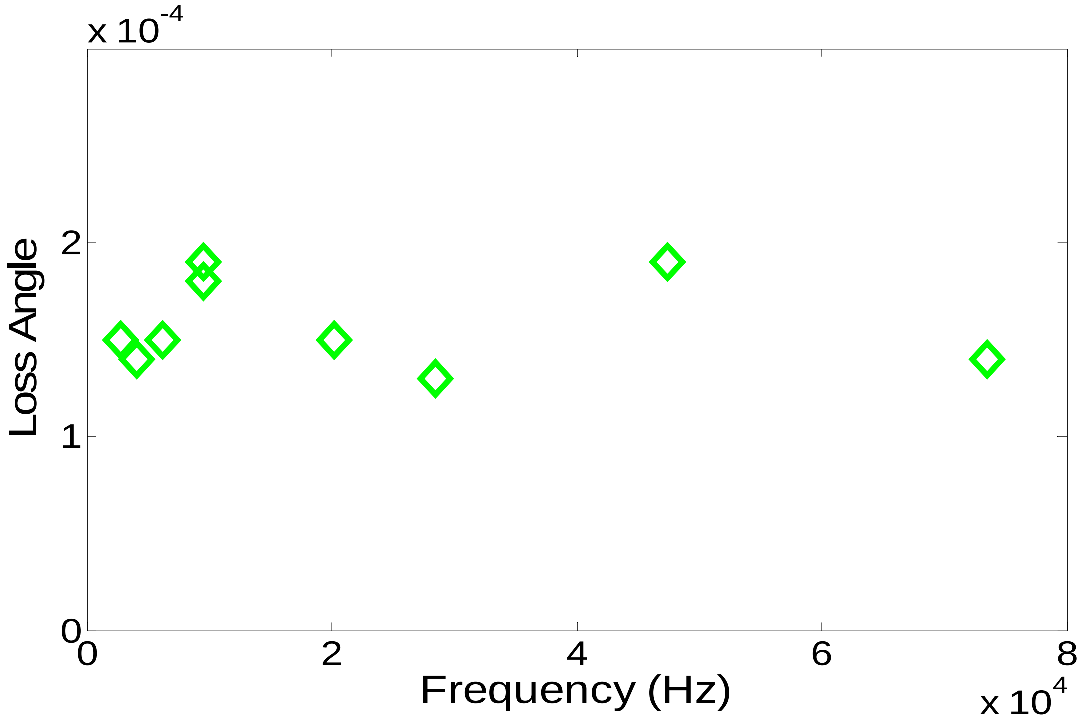
- Formula 3 - SiO_2/Ta_2O_5 doped high [TiO_2]
- LMA/Virgo small coater

Mechanical loss

$\phi = (1.3 +/- 0.1) \times 10^{-4} + (4.7 +/- 3.3) \times 10^{-10} f$

Optical absorption

2.1 ppm – Stanford, 1 ppm – LMA/Virgo



Thin Sample

Frequency	ϕ
2722 Hz	1.5 10^{-4}
4115 Hz	1.4 10^{-4}
6197 Hz	1.5 10^{-4}
8517 Hz	1.9 10^{-4}
9519 Hz	1.8 10^{-4}

Thick Sample

Frequency	ϕ
20221 Hz	1.5 10^{-4}
28457 Hz	1.3 10^{-4}
47402 Hz	1.9 10^{-4}
73521 Hz	1.4 10^{-4}

New Results
Formula 4

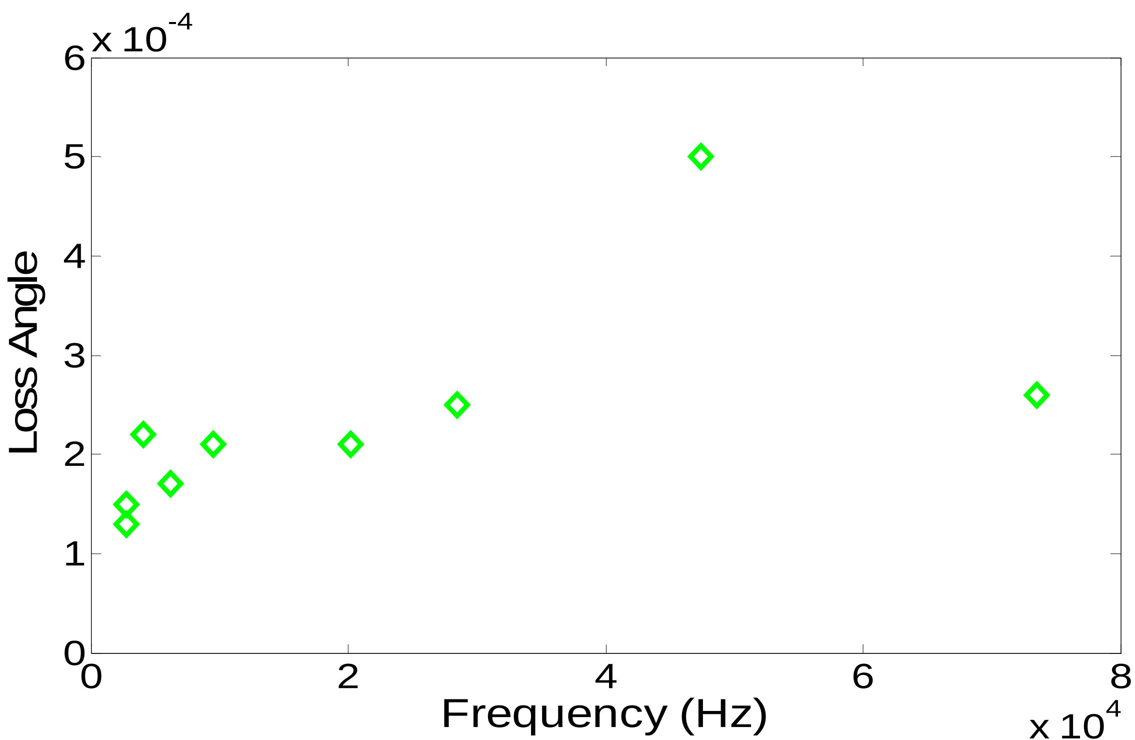
- Formula 4 - SiO_2/Ta_2O_5 doped high [TiO_2]
- LMA/Virgo large coater

Mechanical loss

$\phi = (1.7 +/- 0.1) X 10^{-4} + (1.4 +/- 0.5) X 10^{-9} f$

Optical absorption

1.8 ppm – Stanford, 1 ppm - LMA/Virgo



Thin Sample

Frequency	ϕ
2723 Hz	1.3 10^{-4}
2724 Hz	1.5 10^{-4}
4115Hz	2.2 10^{-4}
6200 Hz	1.7 10^{-4}
9524 Hz	2.1 10^{-4}

Thick Sample

Frequency	ϕ
20221 Hz	2.1 10^{-4}
28457 Hz	2.5 10^{-4}
47402 Hz	5.0 10^{-4} *
73521 Hz	2.6 10^{-4}

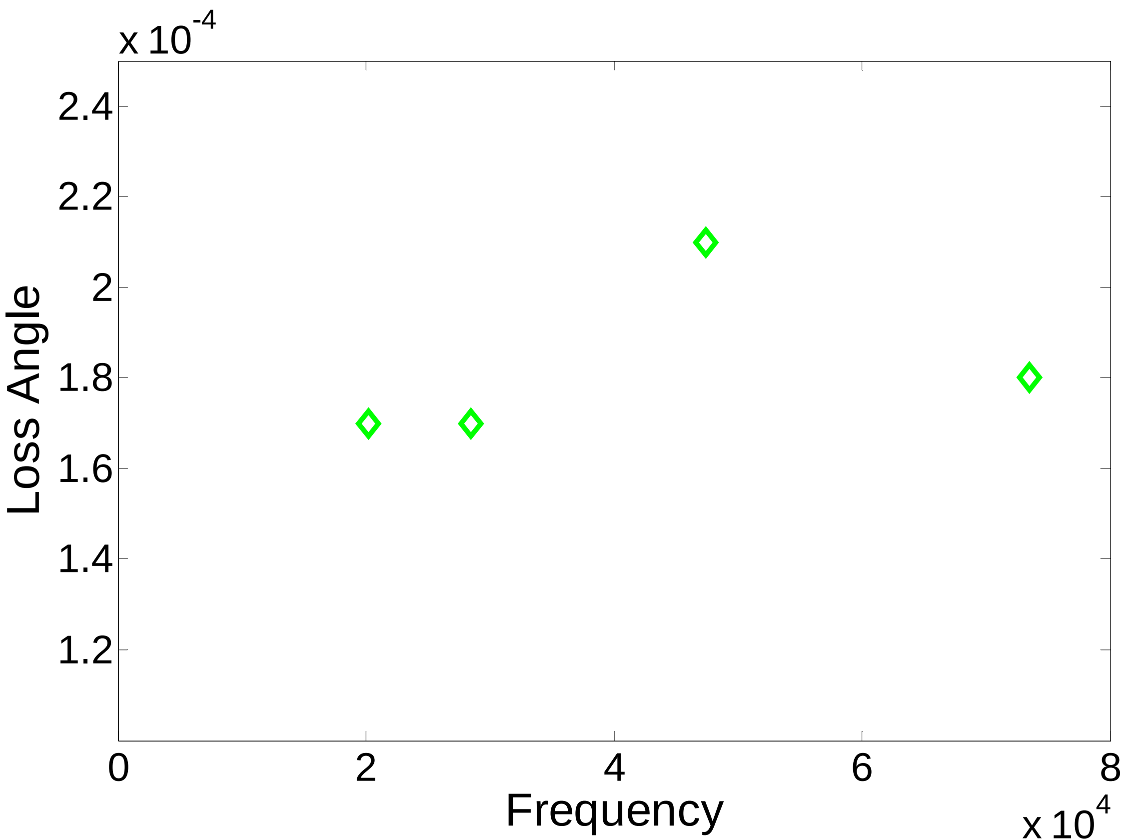
*excluded from fit

New Results
Formula 5

- Formula 5 - SiO_2/Ta_2O_5 doped medium [TiO_2]
- LMA/Virgo large coater
- Thick sample only

Mechanical loss

$\phi = (1.6 +/- 0.2) \times 10^{-4} + (4.1 +/- 5.1) \times 10^{-9} f$

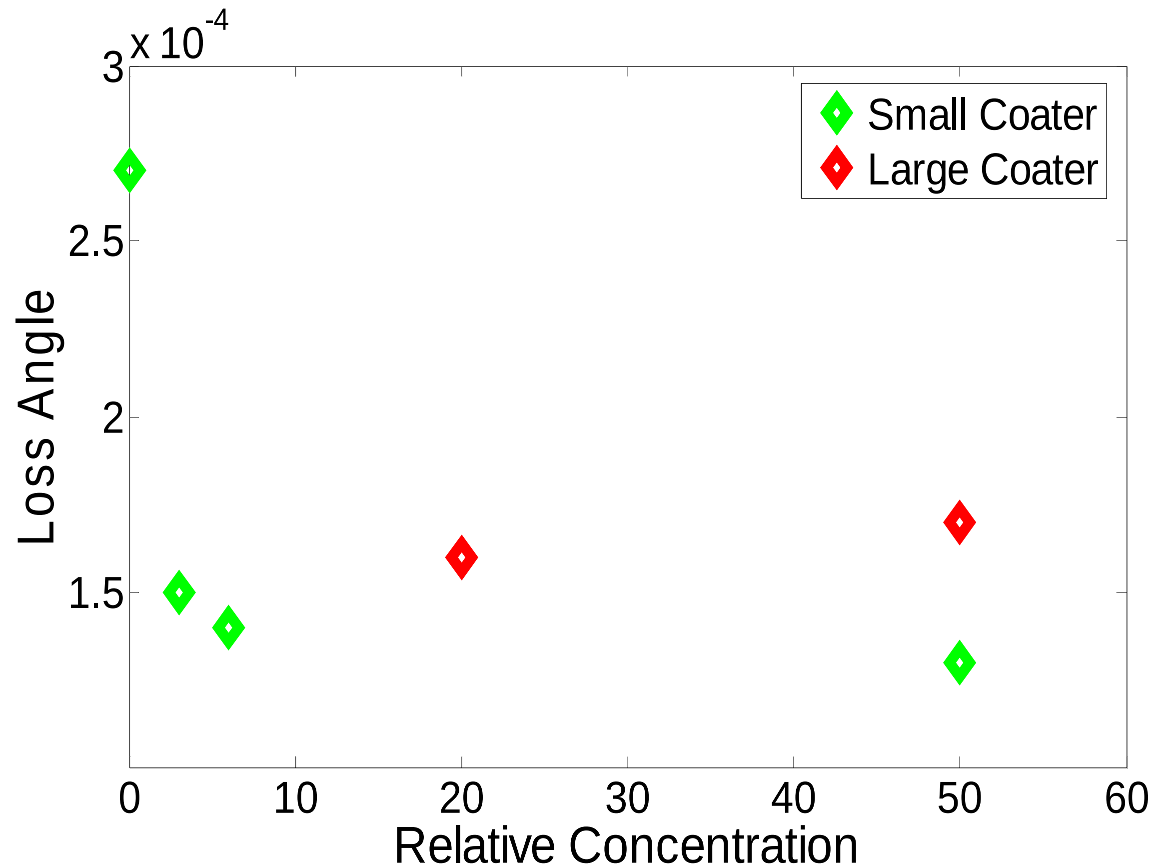


Thick Sample

Frequency	ϕ
20221 Hz	1.7 10^{-4}
28457 Hz	1.7 10^{-4}
47402 Hz	2.1 10^{-4}
73521 Hz	1.8 10^{-4}

Doping of Ta_2O_5 with TiO_2

Loss Angle of SiO_2 /TiO_2 doped Ta_2O_5 at 100 Hz



- Clear improvement with addition of titania
- Problem with the large coater?
- Optimum level of doping?
- Run to run variations?

New Results
Single Layers

- LMA/Virgo small coater
- Thick samples only
- Few nm between 15 layers of tantala

Multilayer measurements

Silica $\phi = (0.5 +/- 0.3) X 10^{-4}$

Tantala $\phi = (4.4 +/- 0.2) X 10^{-4}$

Form. 2 $\phi = (2.4 +/- 0.2) X 10^{-4}$

Mechanical loss

Silica

$\phi = (0.3 +/- 0.6) X 10^{-4} + (-2.1 +/- 1.3) X 10^{-9} f$

Tantala (some cracks seen)

$\phi = (7.0 +/- 2.1) X 10^{-4} + (6.7 +/- 4.4) X 10^{-9} f$

Doped Tantala, Formula 2

$\phi = (2.2 +/- 1.1) X 10^{-4} + (1.6 +/- 2.3) X 10^{-9} f$

Silica – 2.7 μm

Frequency	ϕ
20235 Hz	$0.0\ 10^{-4}$
28473 Hz	$-0.2\ 10^{-4}$
47441 Hz	$-1.4\ 10^{-4}$
73559 Hz	$-1.0\ 10^{-4}$

Tantala – 1.9 μm

Frequency	ϕ
20235 Hz	$6.7\ 10^{-4}$
28473 Hz	$4.2\ 10^{-4}$
47441 Hz	$11.4\ 10^{-4}$
73559 Hz	$11.1\ 10^{-4}$

Doped-Tantala – 1.9 μm

Frequency	ϕ
20235 Hz	$1.7\ 10^{-4}$
28473 Hz	$3.1\ 10^{-4}$
47441 Hz	$3.8\ 10^{-4}$
73559 Hz	$2.9\ 10^{-4}$

In Progress

CSIRO

- Poor stoichiometry
  - Reduced oxygen flow into chamber
  - Preliminary result $\phi \sim 6\ 10^{-4}$
  - Not annealed
- Xenon ions rather than Argon
  - Preliminary result $\phi \sim 4\ 10^{-4}$
  - Argon result $\phi \sim 3\ 10^{-4}$
  - Absorption about 1 ppm

LMA/Virgo

- SiO_2/Ta_2O_5 on sapphire
  - Having difficulty with suspension
  - All SiO_2/Ta_2O_5-TiO_2 coatings
- TNI optics with SiO_2/Ta_2O_5 doped with TiO_2 Formula 2
  - Direct confirmation of thermal noise

Analysis

- Comparison of optical absorption data with mechanical loss
  - All data is in hand

Future Plans

Thermal Noise

- New dopants in Ta_2O_5
  - Cobalt ?
  - Lutetium
    - Ta_2O_5 is oxygen deficient
    - Lutetium is same size
    - Lutetium can oxidize Ta_2O_5
- SiO_2/Ta_2O_5 annealed to reduce stress to zero
  - Annealing cycle has been found
  - May expand to further anneals
- Annealing in ozone
- Much higher [TiO_2] in Ta_2O_5

Other Issues

- Consider handling and cleaning procedures
  - Preserve quality of coatings until they are installed
- Coating with absorption as function of radius in AR
  - Compensate for thermal lensing
- High power test of scatter
  - Seeing problems with scatter in initial LIGO
- Continuing work on Mexican-hat mirrors

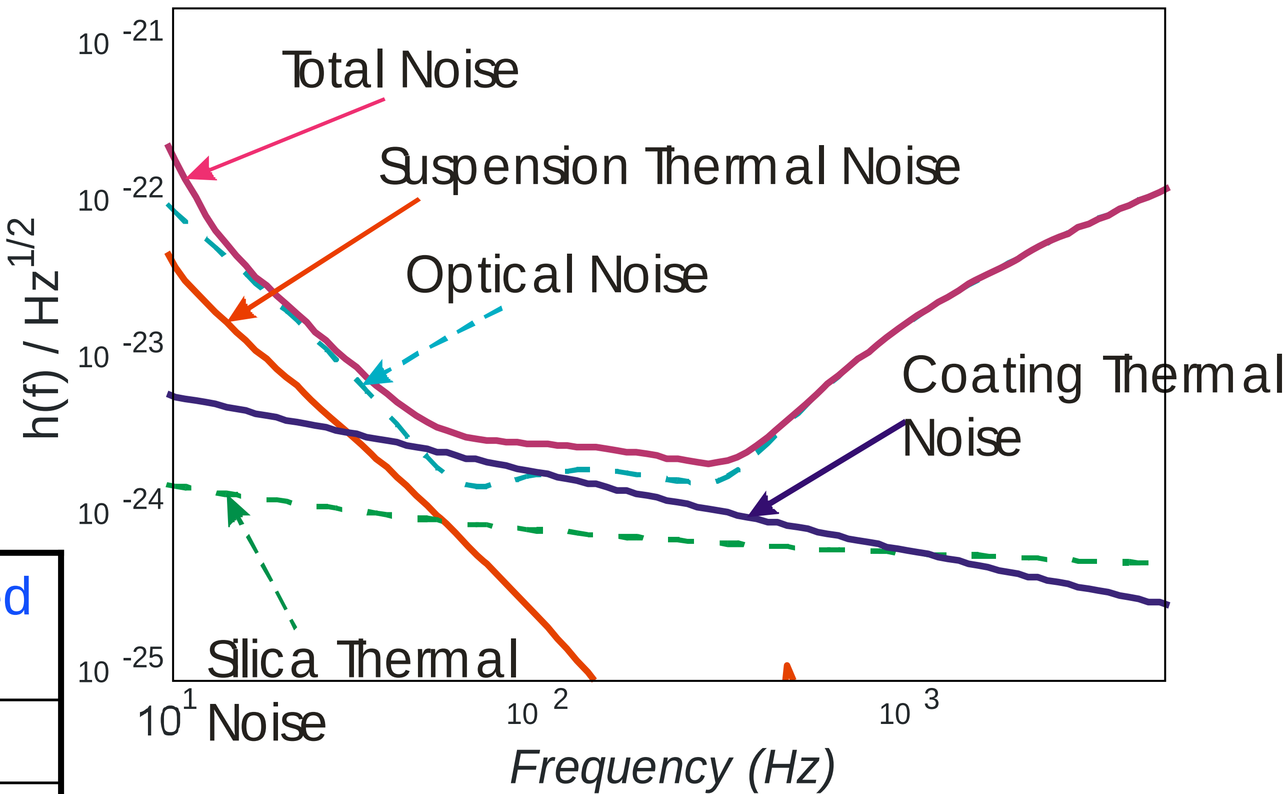
Non-periodic Coatings

- Preliminary work by R. Desalvo with University of Sannio/Salerno using genetic algorithm promising
- Evolve coatings to preserve reflectivity but reduce thickness of Ta_2O_5 needed
- May be able to reduce thickness of higher loss material by ~ 50%
- Concerns about number of layers necessary
- Concerns about required thickness precision
- Concerns with optical absorption
- See following talk by R. Desalvo

Potential Sensitivity with Non-periodic Coatings

- Assume 50% reduction in Ta_2O_5 thickness
- Equivalent to coating $\phi = 8.5\ 10^{-5}$

Source	λ/4 - λ/4 Coating	Optimized Coating
BNS	185 Mpc	210 Mpc
BBH	820 Mpc	930 Mpc
Stochastic	$2.3\ 10^{-9}$	$2.0\ 10^{-9}$
Crab Pulsar	$6.9\ 10^{-7}$	$5.9\ 10^{-7}$



Potential sensitivity with thickness optimized coatings