Caltech, Pasadena, CA

March 20-21st, 2008

2008 Workshop on Optical Coating Noise in Precision Measurement

Abstracts
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Contact Information
Bibliography

T080068-00-R

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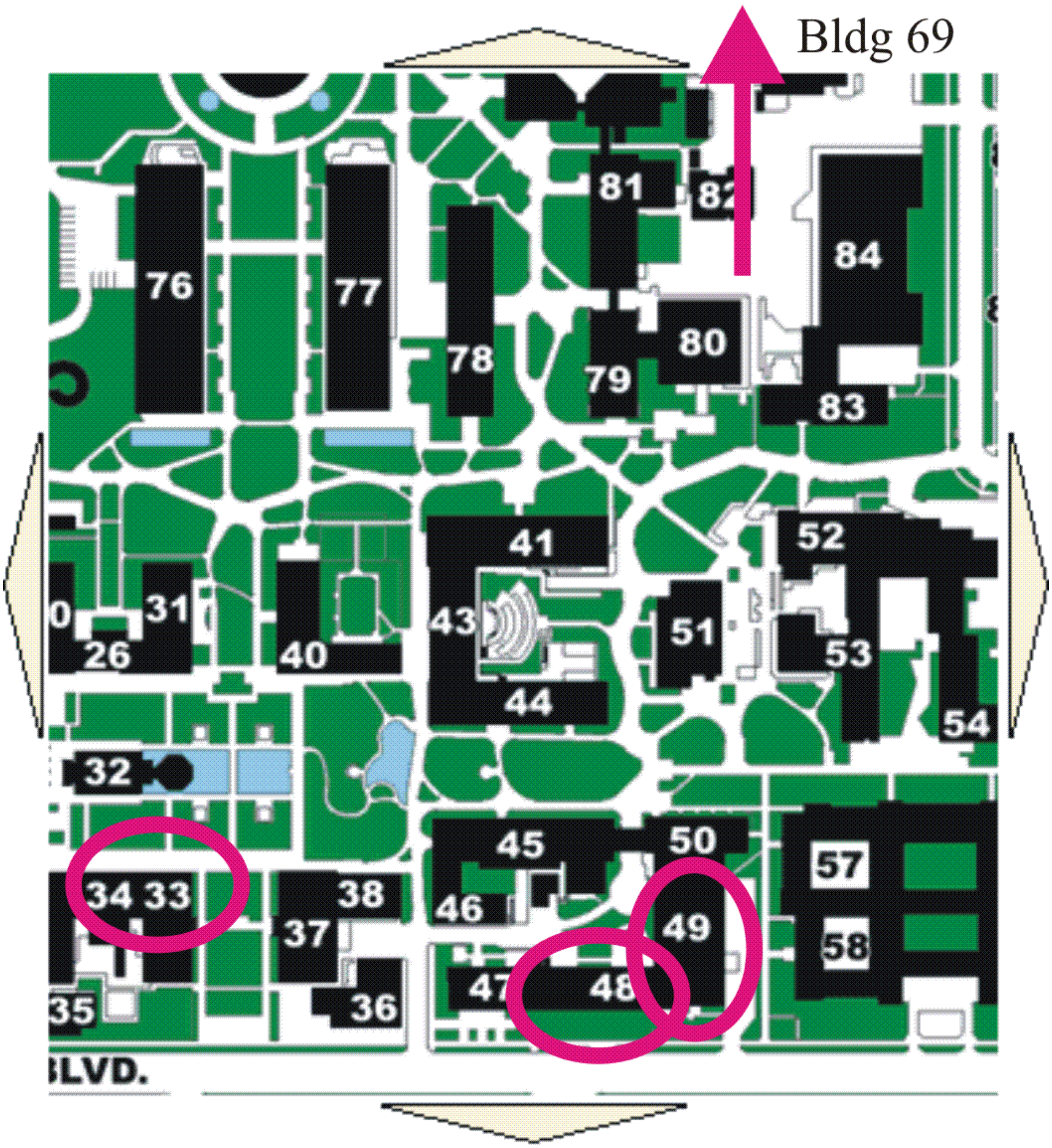

Building 33 (Bridge): 201 – Workshop
012 – Caltech Quantum Optics Lab

Building 48 (Lauritsen): 039 – LIGO Metrology Lab

Building 49 (Synochtron) Thermal Noise Interferometer

Building 69 (Off Map): LIGO 40 meter prototype

Overview: Thursday 1:30 – 3:30

Overview of Ion Beam Sputtering of Optical Coatings

Ramin Lalezari, *Advanced Thin Films, Longmont CO 80501, USA*

An overview of Ion Beam Sputtering (IBS) will be presented. A brief discussion of the history of ion beam sputtering technology will be presented covering the early development of ion sources as propulsion engines for spacecraft and their evolution as deposition sources for optical thin films. The deposition process will be described and compared to other common methods of producing optical coatings. A discussion of the materials commonly sputtered with the IBS process and the film qualities will conclude the presentation.

An Introduction to the Test Mass Mirror Coatings in Advanced LIGO

Steve Penn, *Hobart and William Smith Colleges*

I will present a brief overview of Advanced LIGO and how the goals of that detector establish the requirements of the mirror coatings. We will review the desired optical and mechanical characteristics, and then focus on the challenge of obtaining the low thermal noise threshold.

Macroscopic Tests of Quantum Mechanics with Optical Coatings

Markus Aspelmeyer, *Austrian Academy of Sciences*

There is currently enormous progress towards achieving experimentally the quantum regime of massive mechanical systems. This regime offers fascinating perspectives from quantum-limited sensing applications to the generation of quantum superpositions of macroscopically distinct mechanical states (Schrödinger's cat) that allow for tests of quantum theory in a hitherto unachievable parameter range.

A promising approach has become the use of radiation pressure in high-finesse cavities comprising a suspended mirror, where recent experiments have demonstrated laser-cooling of mechanical modes. Cooling into the quantum ground state is in principle possible with this method but requires large mechanical qualities as backaction provides cooling by damping the system. Coating thermal noise of the suspended mirrors constitutes a fundamental limit for the achievable mechanical quality factors and therefore for the achievable cooling. I will briefly review the current state of the art in these experiments. I will also present some experiments on suspended high-quality optical coatings, where coating thermal noise is the only limiting factor and can be directly accessed by measuring the coating's mechanical properties.

Noise in Precision Frequency Stabilization

Michael J Martin, *JILA University of Colorado*

Coating thermal noise has become a fundamental limitation for state-of-the-art frequency stabilization. To introduce this topic, I will give a brief overview of the Pound-Drever-Hall frequency stabilization technique for high-precision applications, such as frequency standards based on optical-wavelength atomic transitions and gravity wave detection. I will discuss crucial design characteristics for cavity-based optical frequency stabilization, including vibrational and thermal noise sensitivity, and present recent advances in reaching the thermal noise limit with a compact, ultra-high finesse cavity.

Modeling and Theory 1: Thursday 4:00 – 5:20

Imaged Scattered light from LIGO Resonant Cavities: Micro-roughness vs Point Scatter Loss

Bill Kells , *LIGO Laboratory - California Institute of Technology*

Since the beginning of LIGO operation the images of the LIGO arm cavity beams impinging on their end mirrors has presented a puzzle. These images are taken at large observation angles with respect to the beam (cavity axis), so they are of scattered light. The amount and character of such scattered light is of critical interest for interferometer design since it represents the dominant optical power loss from the system. To the extent it can be reduced the interferometer power and hence GW sensitivity can be increased. Although the cavity beam illuminating the end mirrors is smoothly varying in intensity, the imaged scatter is point like, so that the entire image appears as a random, "globular cluster" of un-resolved points. If the mirror surface were perfectly smooth there would be no scatter and no such images. Imperfections (dust, surface flaws, deviations from locally flat in the mirror polish) of the reflecting surface cause the scatter, so that these images of the scattered light contain, in principle, complete information on the nature of the surface imperfections. By now we have collected a large number of very high resolution "globular cluster" images from several interferometer mirrors. Preliminary conclusions from analysis of these digital images will be presented, which clearly indicates distinct micro-roughness background and fixed point (defect) components. These data will be compared then to complimentary conclusions drawn from measurements of the surface scatter by other techniques which are also being used in the project.

Perspectives on Beam-shaping Optimization for Thermal-noise Reduction in Advanced LIGO: Bounds, Profiles, and Critical Parameters

Vincenzo Galdi, *University of Sannio, Italy*

Suitable shaping (in particular, flattening and broadening) of the laser beam has recently been proposed as an effective device to reduce internal (mirror) thermal noise in advanced LIGO. Based on some recently published analytic approximations (valid in the infinite-test mass limit) for the Brownian and thermoelastic mirror noises in the presence of arbitrary-shaped beams, this talk addresses certain theoretical aspects related to the optimal beam-shaping problem. In particular, absolute and realistic lower bounds for the various thermal-noise constituents are derived and compared with the current status (Gaussian beams) and trends (mesa beams), indicating fairly ample margins for further reduction. These outcomes are consistent with some preliminary results obtained by Bondarescu and Chen in connection with Bessel-Gauss-type beams supported by nearly-conical mirrors. In this framework, the effective dimension of the related optimization problem, and its relationship to the critical design parameters are identified, physical-feasibility and model-consistency issues are considered, and possible additional requirements and/or prior information exploitable to drive a multiobjective optimization process are highlighted.

Optical Interferometers with Insensitivity to Thermal Noise

H. J. Kimble, *California Institute of Technology*

A fundamental limit to the sensitivity of optical interferometry is thermal noise that drives fluctuations in the positions of the surfaces of the interferometer's mirrors, and thereby in the phase of the intracavity field. A scheme for possibly reducing this thermally driven phase noise is presented in which a strain-induced phase shift near the mirror's surface cancels that due to the concomitant motion of the substrate's surface. Although the position of the physical surface fluctuates, the optical phase upon reflection can be largely insensitive to this motion in some situations.

A First-Principles Study of Mechanical Properties of Ta_2O_5

Hai Ping Cheng, *University of Florida*

Ta_2O_5 has been tested in the laser interferometer gravitational observation (LIGO) as a candidate dielectric coating material. To understand mechanical loss and thermal noise in the frequency range used in the LIGO experiments, we performed quantum mechanical calculations to study mechanical properties of two Ta_2O_5 polymorphs, which exist at low and high temperature. We compare the calculated properties such as stress tensor, Young's modulus, and Poisson ratio to the experimental results.

Modeling and Theory 2: Thursday 5:40 – 6:40

Fundamental Thermal Noise Limit to Frequency Stabilization of Optical Cavities

Jordan Camp, Kenji Numata, *Goddard Space Flight Center*

We evaluate thermal noise in an optical reference cavity, based on the mechanical loss of cavity materials and the numerical analysis of the mirror-spacer mechanics with the direct application of the fluctuation dissipation theorem. This noise sets a fundamental limit for the frequency stability of an optical cavity of order 10^{-2} Hz /√(Hz) at 100 Hz, and 1 Hz / √(Hz) at 10 mHz, at room temperature. This level coincides with the world highest level stabilization results. The largest contributor to the thermal noise is mechanical loss in the mirror coatings.

Optimization of Coating Design for Reduced Thermal Noise

Innocenzo Pinto, *University of Sannio at Benevento*

The design of non quarter-wavelength multilayer reflective coatings featuring minimal total noise (including Brownian-structural, thermo-elastic and thermorefractive components) for an assigned transmittance is discussed. Results (computational tools, built and planned prototypes) obtained for the simplest binary (two dielectrics) stacked-doublet case are reviewed. Possible generalizations including multi-wavelength, multi-dielectric, and pre-fractal designs are discussed.

Coating Thermal Noise Limits in the MIT Radiation Pressure Experiment

Tim Bodiya, *LIGO Laboratory - Massachusetts Institute of Technology*

The MIT radiation pressure experiment will be limited by solely fundamental noise (quantum noise and thermal noise). I will discuss the prospects for this experiment and the limitations due to coating thermal noise.

Thermal Noise 1: Friday 8:30 – 10:30

Progress and Plans in LIGO Coating Research

Gregory Harry, *LIGO Laboratory - Massachusetts Institute of Technology*

I will discuss what progress has been made researching new coatings for use in LIGO interferometers, focusing on thermal noise performance. I will mention different materials, annealing profiles, and deposition details that have been studied leading to the titania-doped tantala/silica coating that is planned for Advanced LIGO. Finally I will mention plans being formulated for coating research beyond Advanced LIGO.

Thermo-optic Noise in Advanced LIGO and Beyond

Andri Gretarsson, *Embry-Riddle Aeronautical University*

Thermodynamic equilibrium fluctuations in coatings couple into the gravitational wave signal channel through at least three different mechanisms: Mechanical loss, thermo-elastic coefficient, thermo-refractive coefficient. To reduce the noise in Advanced LIGO, and in room-temperature optical cavities in general, these sources of coupling must be reduced. In this talk we discuss measurements of the thermo-refractive coupling component and the implications for Advanced LIGO and beyond.

Measurements of Tantala and Silica as a Function of Temperature

Iain Martin**,** *University of Glasgow*

Thermal noise arising from mechanical dissipation in the mirror coatings is expected to be a significant noise source in both planned and future gravitational wave observatories. Studying the mechanical dissipation in coating materials as a function of temperature is a powerful probe to help identify the underlying physical mechanisms causing dissipation, in addition to testing the suitability of such coatings for use in cryogenic third generation detectors. Our measurements indicate the dissipation peak observed in tantalum pentoxide thin films, with activation energy of 42 meV, is similar to that found in bulk fused silica, suggesting the dissipation may arise from a double well potential corresponding to stable Ta-O bond angles. Identifying the source of the dissipation may lead to possibilities for the reduction of the resulting coating thermal noise. Evidence has also been observed that doping thin-film tantala with titania reduces height of peak in addition to reducing the dissipation at room temperature. Dissipation measurements of thin-film silica will also be presented, and the results compared to published data for bulk silica and silica films deposited by e-beam evaporation and wet thermal oxidation.

The Mechanical Loss of Thin-film Hafnia as a Function of Temperature

Eleanor Chalkley, *University of Glasgow*

The mechanical loss associated with the current dielectric multilayer coatings is a significant source of thermal noise in current and planned gravitational wave detectors. The tantala component of the currently used silica-tantala coatings has been identified as the dominant source of dissipation. Efforts are actively underway to understand and possibly reduce the specific loss mechanism in tantala. In addition to this, studies of other high index materials would be of significant interest. Presented here are preliminary measurements of the mechanical loss of a single layer of ion-beam sputtered hafnia deposited on a silicon cantilever between 5K and 300K.

The Mechanical Loss in Silica and Silica/Alumina Coatings

Steve Penn, *Hobart and William Smith Colleges*

Silica is scheduled to be the low-index component of the Advanced LIGO mirror coatings. To fully understand the loss in the coatings we must determine the loss in silica. This knowledge is essential when designing optimized coatings. We will present the results of our measurements and compare them with the model for bulk silica mechanical loss.

Measurements of Sub-ppm Absorption in LIGO Coatings

Ashot Markosyan, Roger Route, Martin Fejer , *Ginzton Laboratory, Stanford University*

Optical losses in LIGO coated mirrors have been studied using photothermal common-path interferometry (PCI), which is a high-resolution probe-pump technique. Refractive index distortions in the substrate that are caused by thermalized optical absorption coating losses from a localized optical pump beam (λ = 1.064 μ, waist diameter w = 50 μ) result in self-interference across the diameter of a wider probe beam (λ = 632 nm, w = 270 μ). The signal recorded from the interference pattern is directly proportional to the thermalized optical coating losses. This method is capable of resolving optical absorption coating losses at the level of 0.1 ppm using applied pump powers as low as 9 W (equivalent to a pump beam intensity of 500 KW/cm^2).

The PCI technique can be used for studying individual defects as small as 50 μ dia, as well as for carrying out 1- and 2-dimensional surface scans of optical coatings. Characteristic results obtained from various LIGO coated optics that illustrate its capabilities and detection sensitivity will be presented, and further prospective development of the technique for LIGO applications will be discussed.

Thermal Noise 2: Friday 1:30 – 3:15

Thin Film Measurement Facility

Flavio Travasso – University of Perugia

The measurement of losses in coating materials is a great challenge. A lot of different techniques and facilities are used around the world to improve our understanding of them. Our idea is to use a very focused Michelson interferometer to read directly the thermal noise of a thin membrane. The thickness of these membranes is 100 nm (very similar to the thickness of a single layer in a standard coating: 130-182 nm), the diameter is about 0.5mm while the material is sapphire. The membrane is obtained by etching a coated silicon substrate. In this way we have a little free coating without any substrate or rather a little membrane. Performing a FEM simulation we evaluated the rms, about 10^{-10} m – a value comparable with the sensitivity of a good Michelson interferometer.

We plan to obtain the following data:
1) Direct measurement of the coating thermal noise
2) Difference between the coating with and without the substrate: skin-deep stress and annealing behavior.

In this talk I'll present the idea, the status of the facility, the different material we would use in the future, the data we would find and the problems we have to overcome.

Thermal Noise Measured for Optimized Coatings

Akira Villar, *LIGO Laboratory - California Institute of Technology*

The thicknesses of the layers of dielectric coatings can be adjusted to reduce the thermal noise from the coatings. Measurements have been made on mirrors with these "optimized" coatings at the TNI and the results are presented here.

Mechanical loss in coatings at cryogenic temperature

Kazuhiro Yamamoto, *Max-Planck Institute for Gravitational Physics, Albert Einstein Institute*

In the second and third generation interferometeric gravitational wave detector project (LCGT and ET), the mirror will be cooled for the thermal noise suppression. The cryogenic technique is also available for laser frequency stabilization and quantum optics. In order to evaluate how the thermal noise reduces, the investigation about mechanical loss in coating at cryogenic temperature is necessary. I will summarize our and other group's measurement of cooled coating loss and also provide some open questions and applications about cooled coating loss.

Investigations into Non-Gaussian "Mesa" Beams for Future Interferometric Gravitational Wave Detectors

John Miller[1,2], Juri Agresti[2,3], Erika D'Ambrosio[2], Riccardo DeSalvo[2],
Danièle Forest[4], Bernard Lagrange[4], Jean-Marie Mackowski[4],
Christophe Michel[4], Jean Luc Montorio[4], Nazario Morgado[4],
Laurent Pinard[4], Alban Remilleux[4], Barbara Simoni[2,3], Marco G Tarallo[2,3], Phil Willems[2],
Hiro Yamamoto[2]

[1] *IGR, University of Glasgow*
[2] *LIGO Laboratory, California Institute of Technology*
[3] *Dipartimento di Fisica presso Universita di Pisa*
[4] *Laboratoire des Matériaux Avancés*

Test mass thermal noise is expected to pose a significant problem in advanced interferometric gravitational wave detectors. One proposed method of reducing the impact of this noise source involves reshaping the interferometer mirrors to produce a resonant beam with a larger spot size and more uniform intensity distribution. One particular

“Mexican hat” mirror shape gives rise to a class of beams known as “mesa” beams - of which the flat-topped fundamental mode represents a compromise between uniformity of intensity profile and diffraction losses.

These beams have been predicted to reduce all sources of thermal noise (coating, substrate, thermoelastic, thermal lensing) by a non-negligible amount. As such they may find applications in areas of precision measurement outside of gravitational wave research. We present experimental results from a prototype 7 m Fabry–Pérot cavity which has been designed and constructed to study the mesa beam. We show that it is possible to efficiently transform a Gaussian input beam into the mesa shape simply by reshaping the cavity mirrors. We detail the agreement between simulation and experiment of the fundamental mesa mode and its response to mirror tilts. We will present results of work to create a robust locking and alignment scheme for the mesa beam utilizing the well understood Pound-Drever-Hall and wavefront sensing techniques refined using Gaussian beams.

Theoretical results showing the response of a mesa arm cavity mode to thermally induced test mass deformations shall be shown. Estimates of the thermal noise implications of these perturbations shall also be given.

BENCH 7.0: Advanced LIGO Sensitivity Modeling in MATLAB

Clare Bayley, *LIGO Laboratory - Massachusetts Institute of Technology*

BENCH is a Matlab-based tool for estimating various types of noise in Advanced LIGO. BENCH takes input parameters for the LIGO system and optics as well as the astronomical system of operation. The output is a Matlab graph of Power Spectral Density vs. Frequency showing each individual noise source and a summation of all calculated noise sources. BENCH 7.0 introduces a new coating-optimization algorithm, developed by Innocenzo Pinto, which optimizes the layered optical coatings to minimize thermo-optic noise. The program has also undergone a complete restructuring between 6.3 and 7.0, boosting its efficiency and adding a GUI.

Scatter and Optical Loss: Friday 3:15 – 4:15

The Coating Scattering and Absorption Measurements of LIGO I Mirrors at Caltech

Liyuan Zhang, Bill Kells, Lee Cardenas, Helena Armandula, GariLynn Billingsley, *LIGO Laboratory - California Institute of Technology*

To characterize the optical properties of the full size LIGO I mirrors (~250 mm in diameter), a test bench, named RTS system, was established at Caltech in 1997. It was designed to be able to measure and scan the AR coating reflection, HR transmission and scattering at 45 degrees. The RTS system has been upgraded gradually since 2001, new implemented measurements include the birefringence OPD, the bulk and coating surface absorption, total integrated scattering and correlated absorption versus scatter. This report will focus on the HR coating scattering and absorption measurements. The results of the two test masses swapped out from the LIGO interferometer and several spared ones are presented and discussed. As a comparison and calibration, the mirrors of 1" in diameter made with the same technique as for the LIGO I full size mirrors are also measured and discussed.

First Results from the Scatter Imaging Lab at Syracuse

J. R. Smith, *Syracuse University*

The scatterometer at Syracuse makes images of mirror surface scatter for large angles (a few degrees off normal out to close to 90 degrees). A 350mW 1064nm laser is used to illuminate coated mirror samples at their specified angle of incidence, and images are taken over a range of angles using an Apogee U6 astronomical CCD camera. The goals are to measure the scatter versus angle for a given sample and also to determine the amount of scatter at each angle that is from point like defects and micro-roughness glow. In this talk I will present results for the first two samples measured, a commercial HR test mirror and another mirror with a Ti doped Ta/Si HR Advanced LIGO test coating.

Recent Results on the Measurement of Transmission and Scattering Structure on Doped and Non-doped Mirrors

Igor Bilenko – *Moscow State University*

Test facilities installed at Moscow in 2007 allows to measure transmission and to estimate variations of scattering with approx. 1% accuracy and 1 micron spatial resolution. Using 100 mW YAG laser and fine focusing it was possible to apply power density as high as 300 kW/cm^2. Our goal was to check mirrors for the transmission and scattering inhomogeneities and to prove that the optical properties of coatings do not degrade under the high optical power influence. In this talk the first results obtained on the Ti-doped and non-doped mirror samples provided by LIGO Lab are presented and discussed.

Absorption and Thermal Issues: Friday 4:45 – 6:00

Effects of Ultraviolet Irradiation to LIGO Mirror Coatings

Ke-Xun Sun, Nick Leindecker, Ashot Markosyan, Roger Route, Sasha Buchman, M. M. Fejer, Robert L. Byer, *Stanford University*

Helena Armandula, *LIGO Caltech*

Dennis Ugolini, *Trinity University*

Gregg Harry, *LIGO MIT*

We are in the process of investigating the effects of ultraviolet (UV) irradiation on LIGO mirror coatings. We are using UV light from UV LEDs and gas discharge lamps to irradiate several LIGO mirrors with three different coatings recipes: REO, Initial LIGO, and Advanced LIGO. In the first stage tests, we have used UV LED light with a spectrum centered at ~255 nm to irradiate a REO sample for 48 hours with energy deposit of ~2.6 J/cm^2. As a result, absorptive loss from REO coatings increased by ~1.2 ppm. For the Xeon lamp irradiation, the absorptive loss can be increased to ~4 ppm. Further observations have shown that the UV induced loss may be partially recovered by dark storage or by applying high heat. We will present the results UV irradiation experiments. We will further discuss the charge management schemes that may overcome the UV effects.

University of Florida Coatings Damage Test Facility

David Tanner, Daniel Amariutei, Marcus Bagnell, Rodica Martin, Volker Quetschke, Guido Mueller, Dave Reitze, *University of Florida*

A capability for producing and studying damage to high-reflectivity coatings is being developed. A 100 W Nd:YAG laser is focused to a 50 micron spot size at the surface of the coating under study. The mirror is located in a UHV environment. The laser spot can be scanned across the sample and the laser power and intensity may also be adjusted automatically.

Biographies and Contact Information

Markus Aspelmeyer - Institute for Quantum Optics and Quantum Information (IQOQI) of the Austrian Academy of Sciences

Markus Aspelmeyer is a Senior Scientist at the Institute for Quantum Optics and Quantum Information (IQOQI) of the Austrian Academy of Sciences, where he leads the quantum-opto-mechanics team. He is an expert in experimental quantum optics and in quantum entanglement with a background in solid-state physics obtained during his PhD work (LMU 2002) at the Universities of Munich, Germany, and Houston, TX. He is a member of the Foundational Questions Institute (FQXI) and recipient of a Feodor Lynen Fellowship of the Alexander von Humboldt Foundation (2002), the Ignaz L. Lieben Award of the Austrian Academy of Sciences (2007) and the Fresnel Prize of the European Physical Society (2007).

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Garrett D. Cole - Lawrence Livermore National Laboratory

Dr. Garrett D. Cole, postdoctoral researcher LLNL, is an expert in the development of optical microsystems, specifically in the area of tunable optical resonators in compound semiconductor materials. Dr. Cole received the B.S. degree in materials engineering from the California Polytechnic State University, San Luis Obispo, in 2001, and the Ph.D. degree in materials, with a specialization in electronic and photonic materials, from the University of California, Santa Barbara in 2005. At UCSB his dissertation research focused on the development of micromechanically-tunable vertical-cavity laser amplifiers. Dr. Cole's current research interests center on novel optical microsystems for sensing and communication, with an emphasis on the development of novel structures for quantum optomechanics.

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Andri Gretarsson - Embry-Riddle Aeronautical University

BSc (Hons): University of Edinburgh
PhD: Syracuse University. Thesis was on thermal noise and other noise sources in suspension fibers for low noise pendulums such as in LIGO. Thesis Advisor: Peter Saulson
Postdoc: Caltech-LIGO Livingston Observatory
Current Position: Assistant Professor of Physics at Embry-Riddle Aeronautical University (Prescott, AZ). Working on measurements of various coating properties, including mechanical loss, thermo-refractive coefficient, and scatter.

Gregory Harry – MIT LIGO Laboratory

I am a research scientist at MIT working on LIGO where I specialize in materials issues. I have been the LIGO Cognizant Scientist for coating research since 2000, and am also active in research on silica and sapphire substrates and charge noise issues. Materials issues related to thermal noise are a particular area of specialty as my active laboratory research focuses on measuring mechanical loss in coated and uncoated samples.

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H. J. Kimble – Caltech

The general areas of my research are Quantum Optics and Quantum Information Science, including the creation and utilization of manifestly quantum states of the electromagnetic field. Beyond their fundamental interest, nonclassical states of light have enabled diverse scientific advances, such as measurement sensitivity beyond the standard quantum limit. I have devoted considerable effort to the field of cavity quantum electrodynamics in a quest to attain strong coupling, which requires small optical cavities of the highest possible finesse. A current experiment involves a single atom trapped in a Fabry-Perot cavity with finesse ~500,000 and critical photon number ~ 0.005.

Ashot Markosyan - Ginzton Laboratory, Stanford University

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Iain Martin – University of Glasgow

I am a graduate student in the Institute for Gravitational Research at Glasgow University, and will take up a post-doctoral research fellowship in the Institute in October 2008. My research focuses on low mechanical dissipation materials to reduce the thermal noise in the suspensions, mirror substrates and particularly in the reflective mirror coatings of future detectors. I currently measure the mechanical dissipation in coating materials as a function of temperature, in an effort to identify the mechanisms responsible for the dissipation and to test coatings for possible use in future cryogenically cooled detectors. My measurements of a dissipation peak in tantalum pentoxide have provided the first evidence towards identifying the dissipation mechanism in this material. I am also interested in the microscopic structure of the coating and how this is related to the deposition technique and annealing conditions.

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Michael J. Martin – JILA University of Colorado

Mike Martin is currently a graduate student at JILA with Jun Ye's group. His active research includes an atomic clock based on laser cooled Strontium atoms, and femtosecond frequency combs. He did his undergraduate work at Harvey Mudd College, in Claremont, CA.

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Innocenzo Pinto – University of Sannio at Benevento

Innocenzo M. Pinto received the MS degree in Electrical Engineering from the University of Naples "Federico II" in 1976. Winner of national competitions he became Assistant Professor of Electromagnetics in 1983, Associate Professor in 1987, and Full Professor in 1990. From 1998 he joined the University of Sannio at Benevento where his research activity is focused on Electromagnetic Theory and Applications, Gravitational Wave Experiments, Signal Theory and Applied Mathematics.

Steve Penn – Hobart and William Smith Colleges

Steve Penn is a professor at Hobart and William Smith Colleges in Geneva, NY. He received his PhD in 1994 from MIT in Nuclear Physics. He held two postdocs at University of Washington (EötWash group) and Syracuse (Saulson's LIGO group) before joining HWS. His work is focused on thermal noise in the test mass substrates, mirror coatings, and suspensions.

Josh Smith – Syracuse University

BSc. Syracuse University 2002. Did research in Peter Saulson's group with Gregg Harry, Steve Penn and Andri Gretarsson. Undergraduate research thesis project was on effects of silicate bonds on thermal noise of silica rods.

PhD. University of Hannover 2006. Graduate research assistant in Karsten Danzmann's group at the AEI Hannover. Research focus on commissioning and characterization of the GEO600 gravitational wave detector. Also measured the in situ quality factors of the GEO600 monolithically-suspended test masses.

Research Associate Syracuse University 2007-present. Tasks include enhanced LIGO commissioning, control room software development and the scatter imaging lab.

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Ke-Xun Sun - Stanford

Ke-Xun Sun is interested in LIGO and LISA science and technology. He has been working on interferometers, gratings, modular gravitational reference sensors, optical sensing, UV LED charge management, and now on LIGO optics and coatings. He is a Senior Research Scientist at Stanford University. Concurrently, he is a Senior Scientist at DOE complex at Livermore.

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