LIGO-G980137-00-M

A Renewal Proposal for the Stanford Program

Faculty

Robert Byer - Lasers and Interferometry
Dan DeBra and Jonathan How - Suspensions, Isolation and Control
Martin Fejer - Materials, Lasers and Interferometry
James Harris - High Power Photodiode Development
Robert Wagoner - Data Analysis and Sources

History

10 watt Laser Development 1991 -1995
GALILEO 1996 -1999
MRI Funding ETF Vacuum System 1998
Currently Proposed Stanford Program 1999 - 2002

SCANNED

Stanford Gravitational Wave Interferometry Group

Faculty

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Visiting Scholars

Ray Beausoleil

Outline of Presentation

Martin Fejer

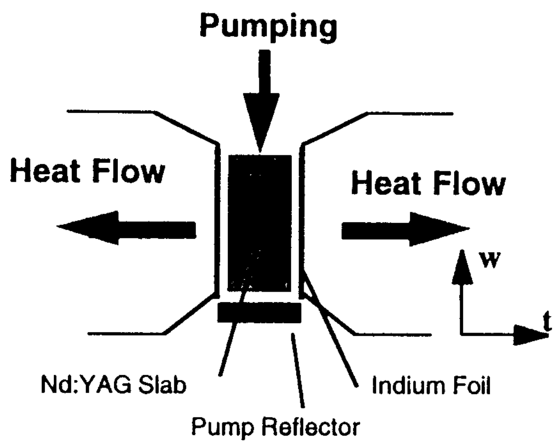
- Previous work
- Lasers and Optics
- Suspension and Core Optic Materials
- High Power Photodiode Development
- Advanced Configuration

Daniel DeBra

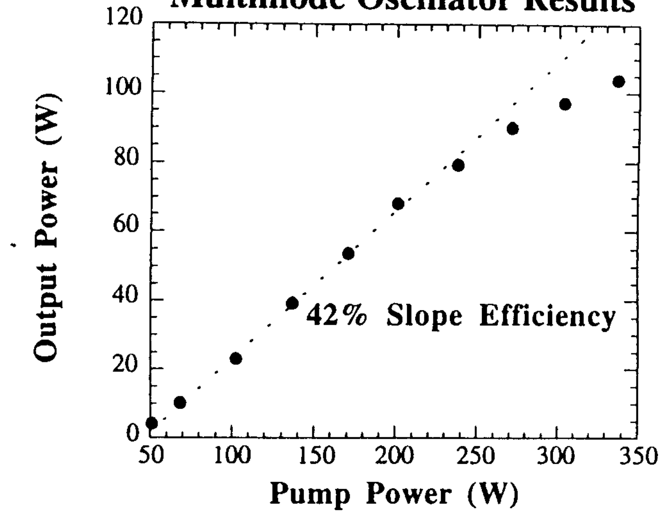
- Previous Work
- Suspensions, Isolation, Alignment and Control
- Engineering Test Facility

Prior Work on Lasers and Optics

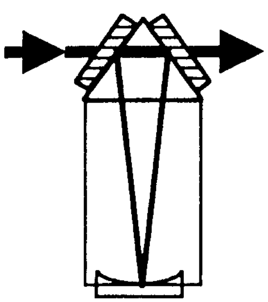
Edge-Pumped, Conduction-Cooled Slab Design



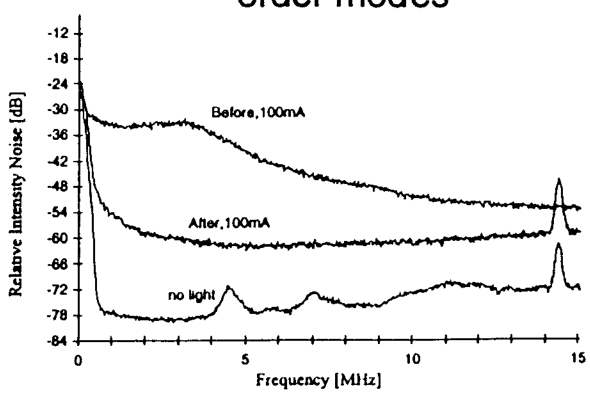
Multimode Oscillator Results



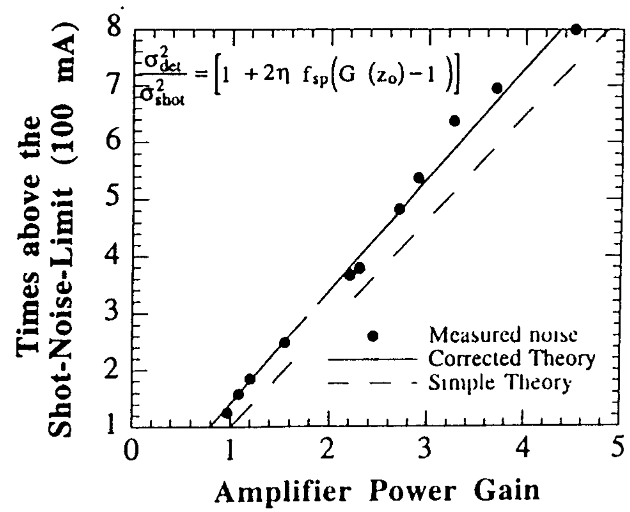
Pre-Mode Cleaner



0.1% in higher order modes



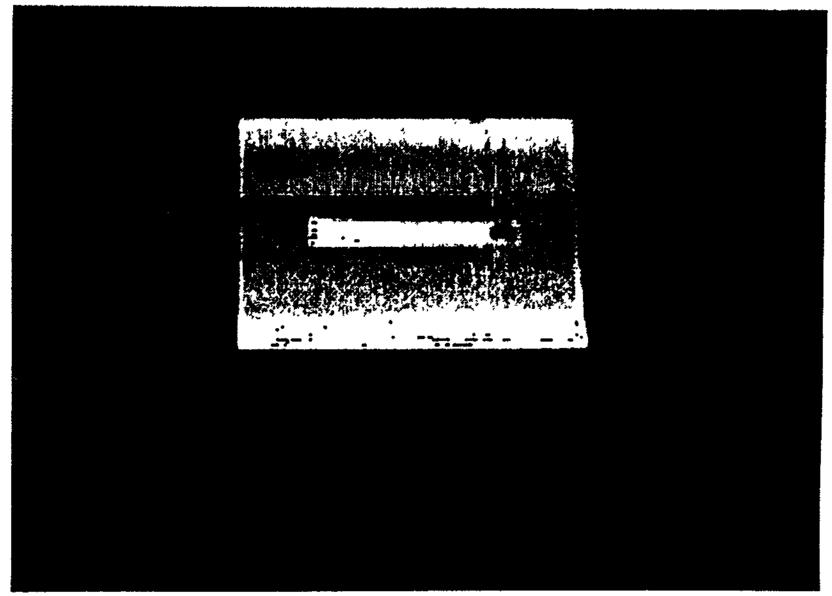
Unsaturated Amplifer Power Noise



Prior Work on Suspensions and Test Mass Materials

Sapphire acoustic resonators

Sapphire cantilever



Hydroxy-catalysis bonding

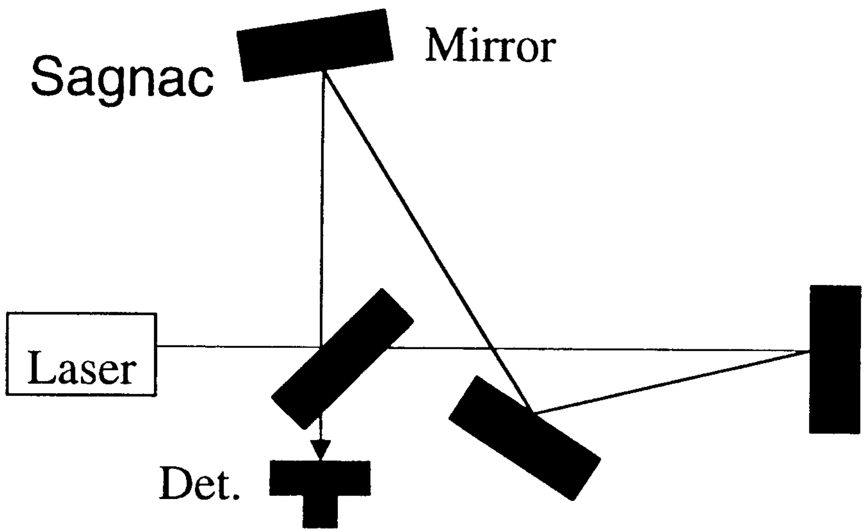
Silica - silica
Silica - sapphire
Silica - YAG
Sapphire - sapphire
YAG - YAG

Optical absorption measurements by common path photo-thermal interferometry

Sapphire 50 ppm/cm

YAG 100 ppm/cm

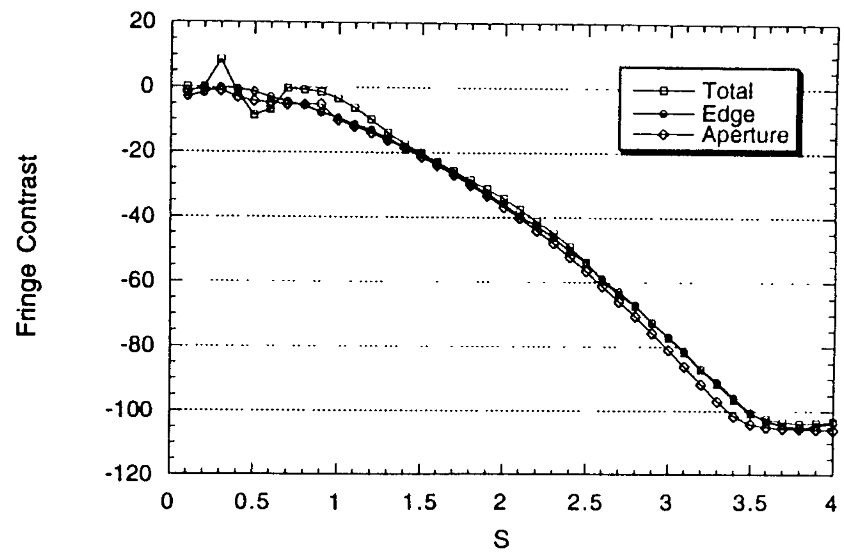
Prior Work on Advanced Configurations



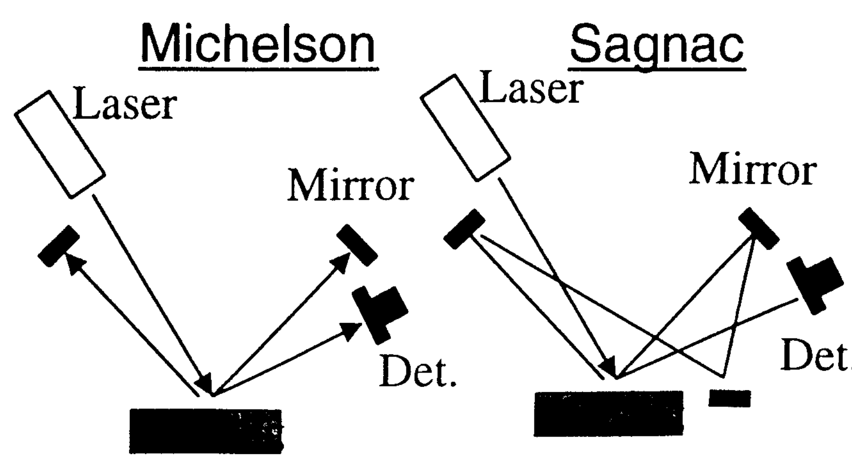
- Proposed using Sagnac as A GW detector and showed low frequency sensitivity (Sun PRL 1996)
- Common path local oscillator signal extraction (Sun OL 1997)
- Reciprocal port signal extraction (Beyersdorf 1998)

Delay Line

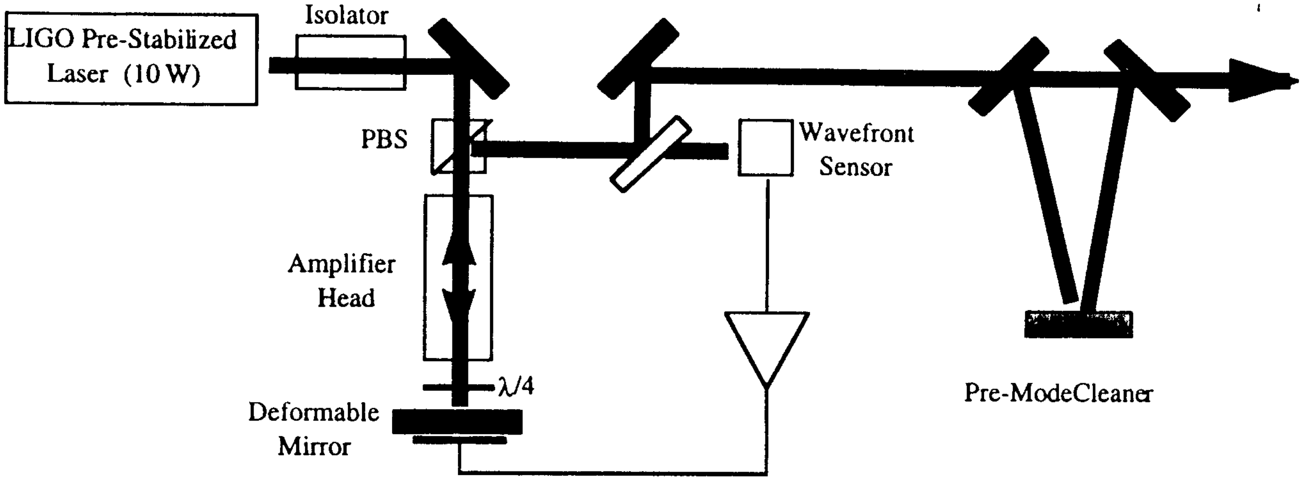
70 bounce, 532 nm, 85 cm Diameter



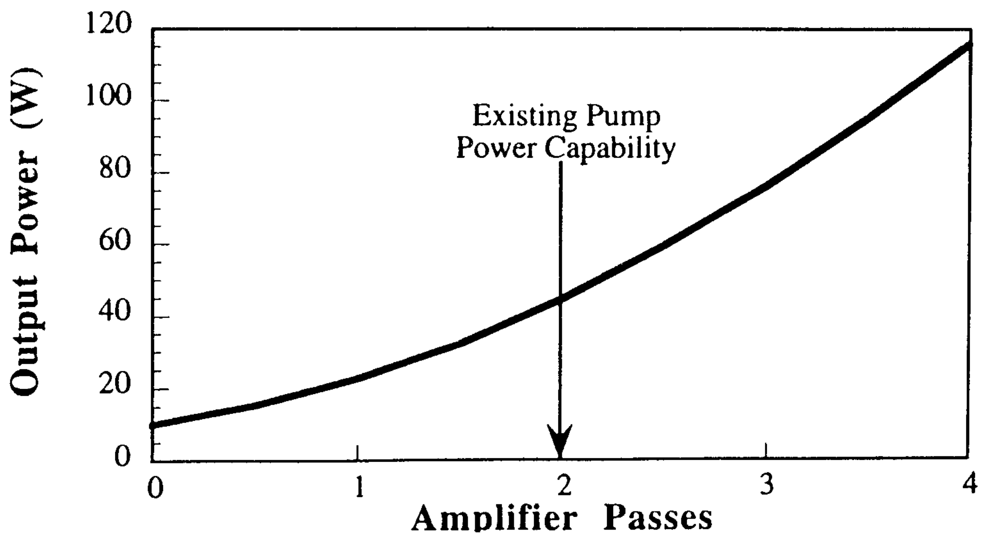
All Reflective Interferometers



Lasers Amplifier Module



Dual Double-Pass Amplifier Calculation



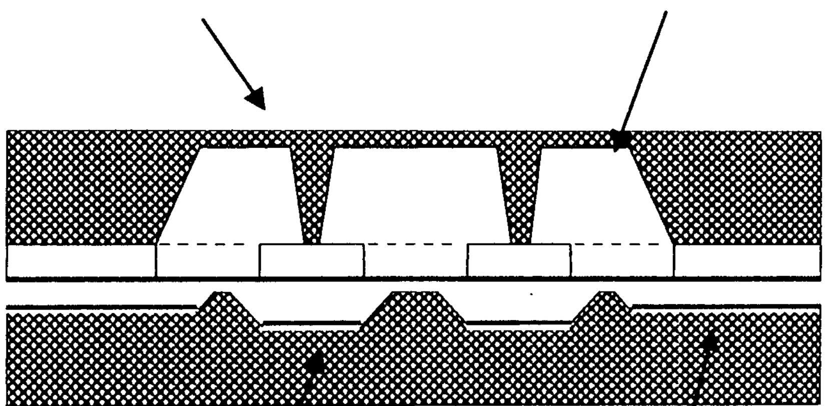
Master Oscillator
- 10 W PSL

Power Amplifier #1
- 40 W Output Power

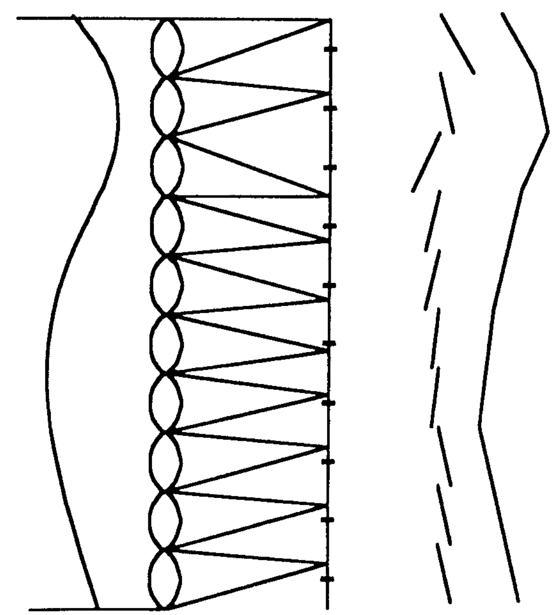
Power Amplifier #2
- 117 W Output Power

Adaptive Optics

Deformable Mirror



Wavefront Sensor

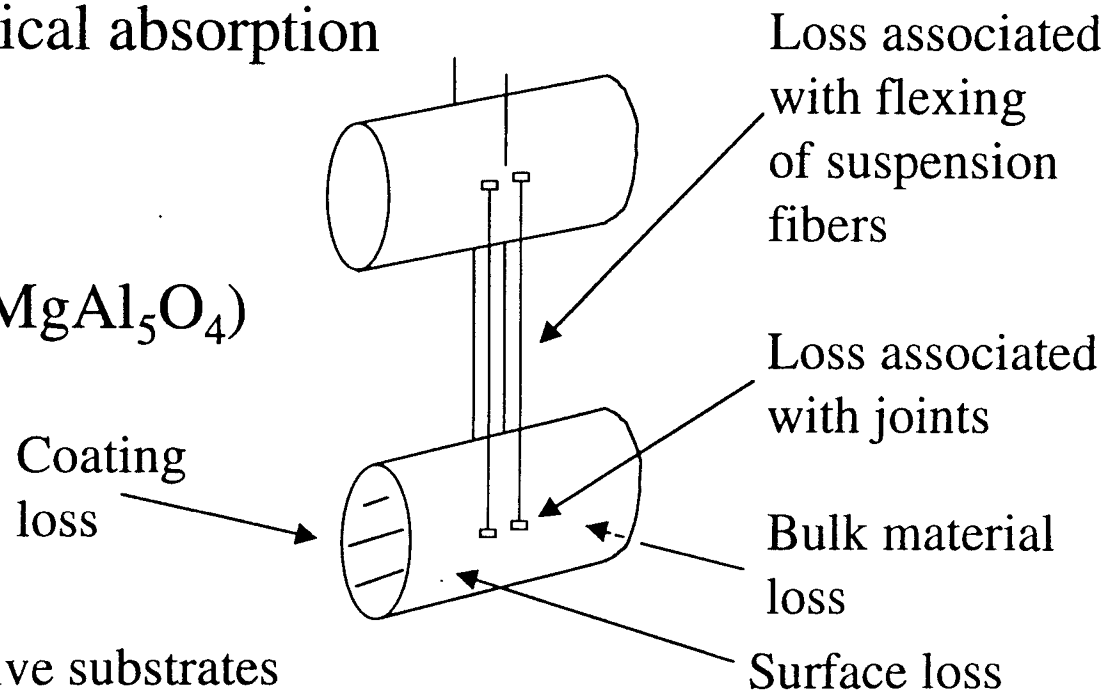


Limits to sensitivity: test masses and suspensions

- Thermal noise due to mechanical loss
- Thermal loading due to optical absorption
- Candidate materials:

  Sapphire, Silicon,

  YAG ($Y_3Al_5O_{12}$), Spinel ($MgAl_5O_4$)



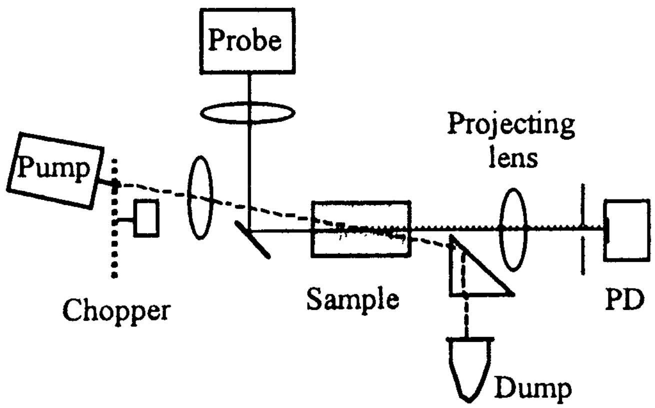
Important to characterize:

- Absorption loss in transmissive substrates
- Mechanical quality (Q) factors of : bulk substrate materials

  materials in form of fibers and flexures
- Bonding techniques for jointing crystalline materials and fused silica
- Effects of surface preparation and coatings on Q factors and optical losses

Advanced Materials: Optical Absorption

Common-path photothermal interferometry



Simple highly sensitive absorption measurements

0.1 ppm/cm in Sapphire @ 4 W
0.1x0.1x0.3 mm^3 resolution

Potential Core Optics Mat'ls
- Sapphire (Al_2O_3)
- YAG ($Y_3Al_5O_{12}$)
- Spinel ($MgAl_2O_4$)

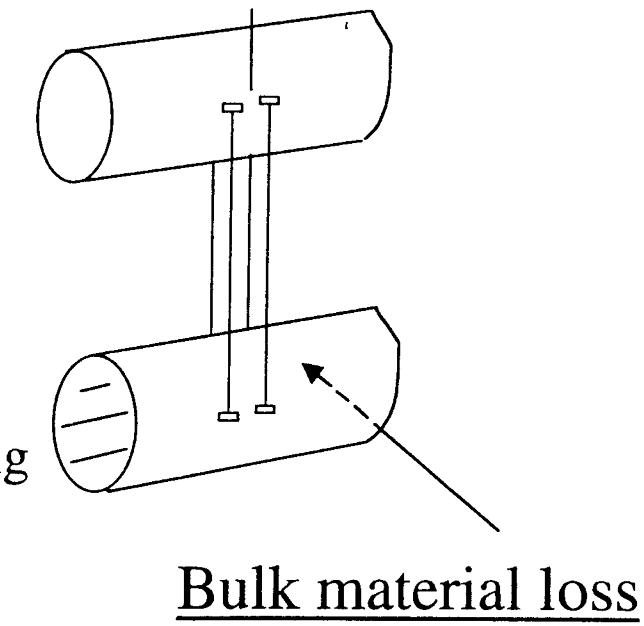
Sapphire Development

Current losses: 50 ppm/cm

Suspect: Ti^{3+}/Ti^{4+} equilibria

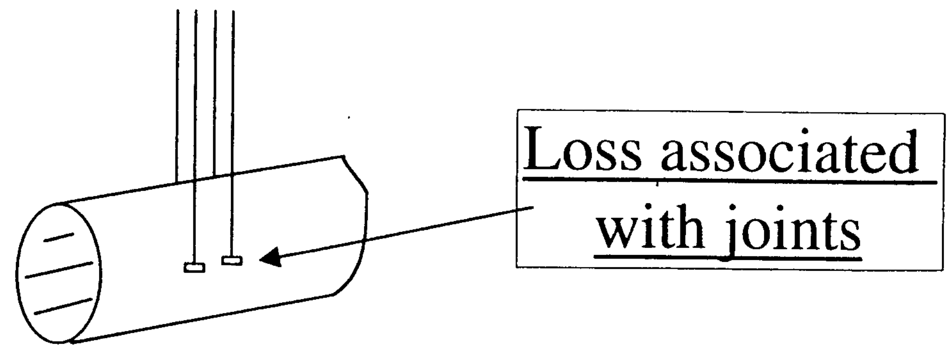
Compare: doped/undoped
oxidized/reduced
absorption/fluores.

Test mass Q



- Q of resonant mode measures $\phi(\omega_0)$
  - Ideally influenced only by bulk properties
  - Can be influenced by processing and mounting
- Loss measurements
  - Ringdown: Stanford;GEO (Glasgow);LIGO
  - Anelastic aftereffect : Syracuse
- Characterize candidate materials
  - Silicon, YAG
- Monitor improvements in processing and bonding
  - Fused silica, Sapphire

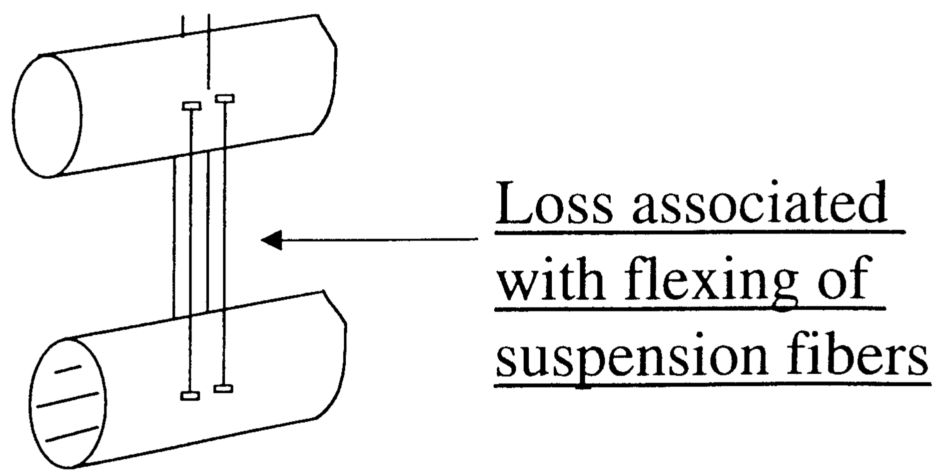
Bonding and Q measurements



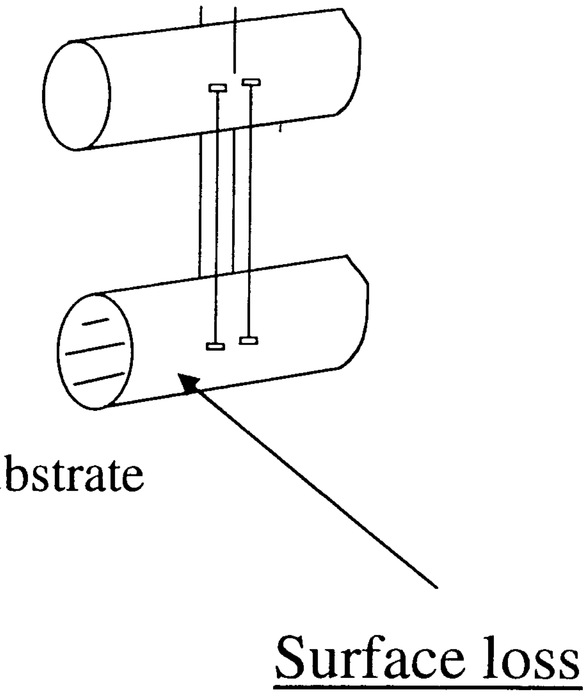
- Low-loss, low-creep suspension attachment essential
- Silicate bonding (J. Gwo) developed for all-fused silica telescope in GPB project
  - High strength room temperature process attractive for suspension fabrication
  - Extremely low loss demonstrated(Glasgow/Stanford)
- Fused silica/fused silica studies
  - Systematics of strength and loss
  - Creep
- Advanced materials
  - Fused silica - crystalline materials
  - Crystalline - crystalline materials
  - Bonds to metals (?)

Suspension materials

- Advanced LIGO baseline: cylindrical fused silica fibers
  - Reduced low frequency noise vs wire
- LIGO III issues: cylindrical fused silica
  - Room temperature - strength/loss too low
  - Cryogenic - silica loss increases rapidly
- Potential solutions
  - Room temperature : fused silica ribbons
  - Cryogenic: crystalline fiber/ribbon
- Research directions
  - Fabricate:
    - Variety of methods
  - Characterize:
    - Flexure ringdown
    - Violin mode Q
- Collaborate with Glasgow and LIGO on silica ribbons

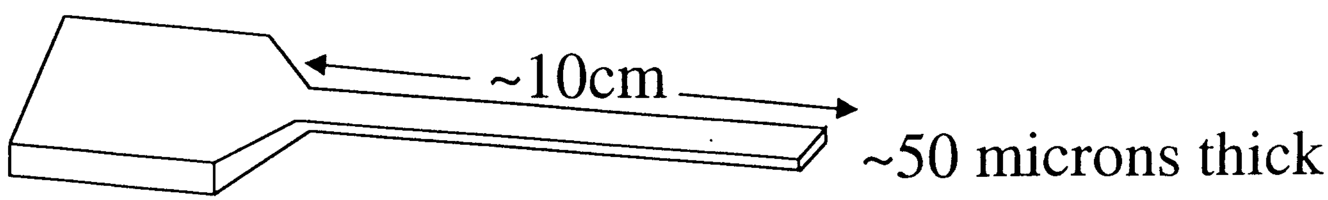


Surface preparation and coating



- Surface preparation and coating may affect Q
  - Lossy layer due to surface damage
  - Polycrystalline coating may be lossier than bulk substrate
  - Strongest effect for largest surface to volume ratio

- Study small resonators
  - Easier characterization of processing effects
  - Develop low loss flexures
  - Silica and advanced materials

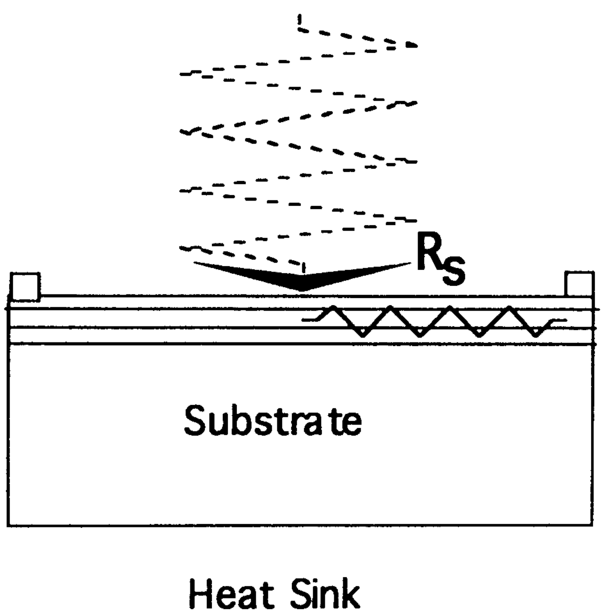


Green's Function Approach to Calculating Thermal Noise

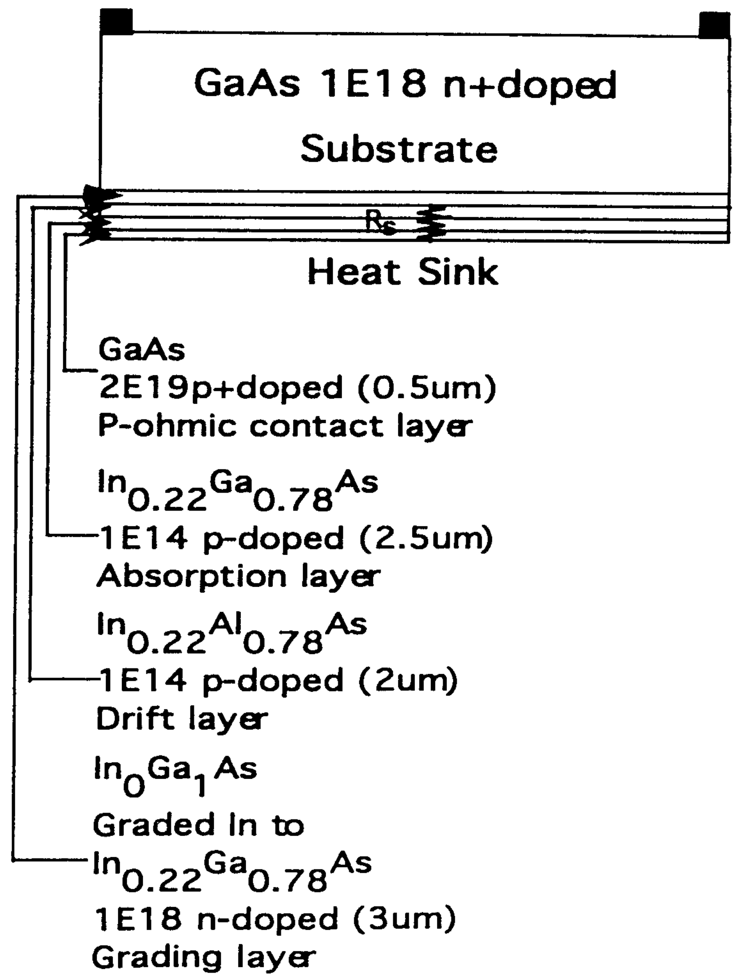
- Original development relating Green function and two point correlation function (Nakagawa et al, RSI 1997)
- Current and Future Work with Nakagawa (Ames Lab)
  - Delay line and Fabry-Perot
  - Anisotropic materials (Sapphire)
  - Spatially inhomogeneous loss
  - Intuitive model problems

High power photodiode development

Conventional Photodiode



Proposed Photodiode



Future improvements for photodiode

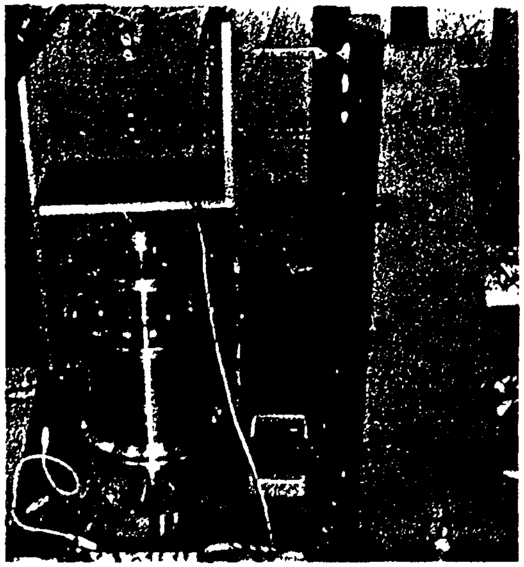
- Back-side Illumination Structure
  - Decrease Series Resistance between absorption Layer and contacts
  - Very short carrier transient length
  - Constant resistance independent of intensity and illumination area
- Low Temperature Growth Material
  - High Resistance : $10^6 \sim 10^9$ M
  - High Breakdown Electric Field : $4 * 10^5$ Vcm^{-1}
  - Adjustable Carrier Life Time : ns to ps
  - High Mobility : $2000 cm^2 V^{-1} s^{-1}$
  - Controllability of Electrical and Optical Properties by Annealing
  - High Thermal Conductivity due to Better Crystal Structure
  - Extremely Low Background Doping level (less than $10^{10} cm^{-3}$)
  - Adjustable Bandgap Energy due to Deep Defects
  - Ability to decrease capacitance by thick intrinsic layer

Suspensions, Isolation Alignment and Control

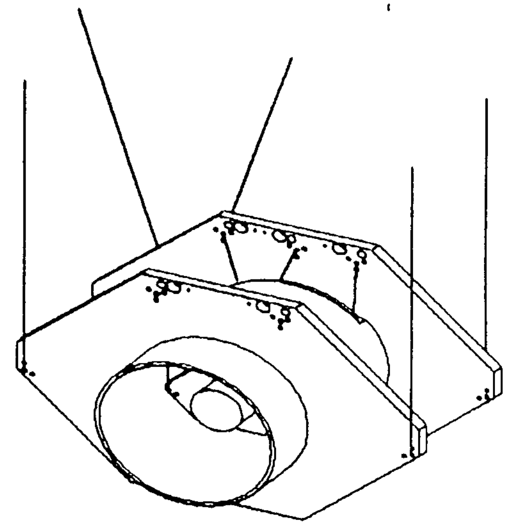
Dan DeBra

Aeronautics and Astronautics
and Mechanical Engineering Department
Stanford University

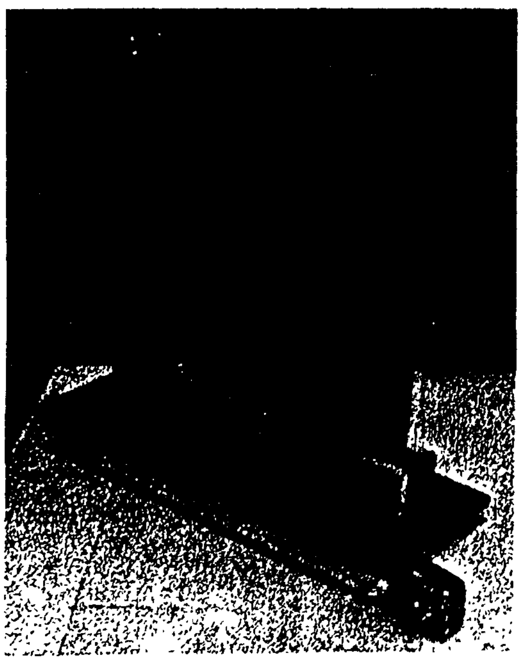
Previous Work Suspensions Isolation and Control



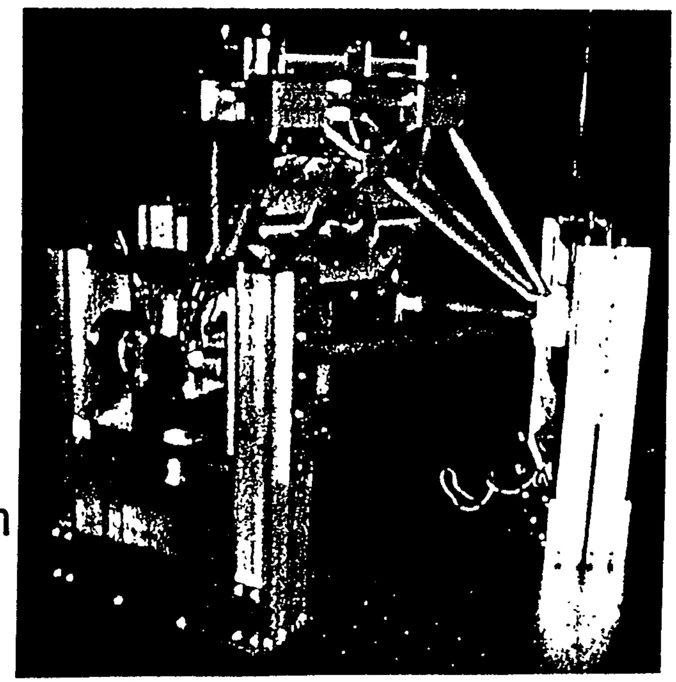
One -DOF active strut on test stand



Five wire coaxial double suspension



Low frequency Barn door seismic sensor



Six -DOF active platform

LI GO II and LIGO III

- LIGO II Minimum
  - Active isolation to lower RMS motion of test mass
  - Eliminate (or minimize) actuation on test mass
- LIGO II Advanced
  - Improve isolation via active/passive isolation to realize benefit
  - of lower thermal noise
- LIGO III Minimum
  - Additional active isolation and possibly extra sensor/actuator layers
  - Integration of auxilary interferometric length measurement beams
- LIGO III Advanced
  - Extra low-frequency isolation

Issues on Suspension, Isolation, Alignment and Control

- Pendulum thermal noise
- Test mass thermal noise
- Actuator noise
- Low frequency (<10 Hz) alignment
- Vertical isolation in the measurement band

Command Authority Reallocation

Effect control as far from the test mass as possible

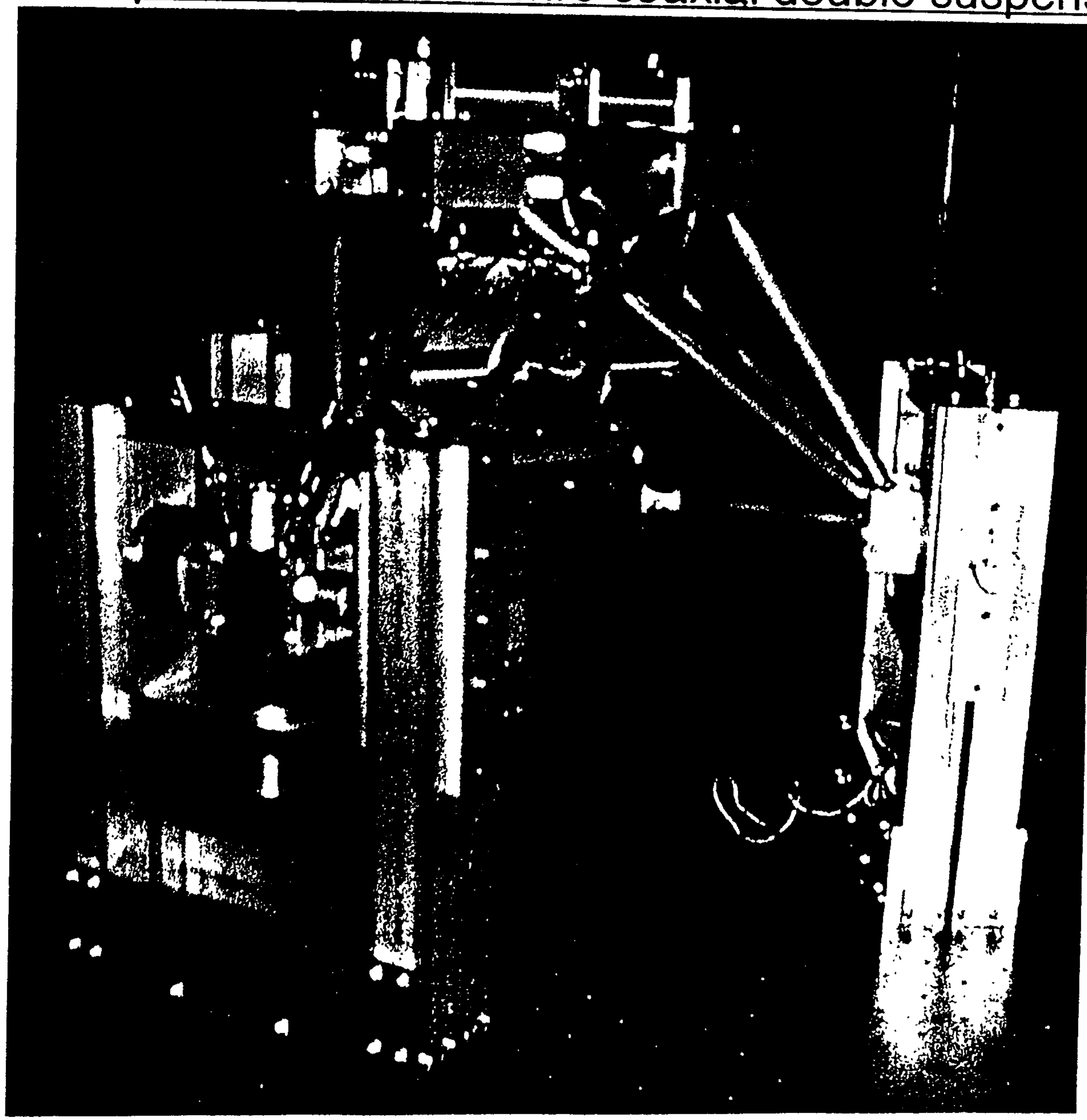
Benefits

- minimizes sensor and actuator noise
- a clean test mass has lower thermal noise
  - If command to test mass cannot be eliminated then at least reduce to the point where electrostatic or radiation pressure can be used
- compatible with feed forward

Current and Proposed Active Alignment and Isolation

- Very high gain required to achieve out of band seismic reduction
- Hexapod for low frequency alignment and high frequency isolation
  - 6 DOF Isolation and alignment
  - Collocated sensors and actuators
- Possible insert for LIGO II

Six DOF Active platform with five wire coaxial double suspension



Systems Level Design of LIGO III

Sensing

Alignment sensor priorities
- Length
- pitch and yaw
- lateral translation
- roll sensors

Relative stage displacement
Low frequency seismometers

Actuation

Minimum authority near test mass

Plant

Low stress (>10 Hz natural frequency)
Kinematic Design
Structure damping

Control laws

- Mimo
- Control authority reallocation
- Feedforward

ETF Schedule for Fall 1998 - Fall 2002

	LSC Schedule	Vacuum System
Sep-98		Pumps
Oct-98		
Oct-98		Spool
Nov-98		
Dec-98		
Jan-99		Chambers
Feb-99		Assembled
Mar-99	Summit	Tested
Apr-99	PDR	
May-99		
Jun-99		
Jul-99		
Aug-99		
Sep-99		
Oct-99		
Nov-99		
Dec-99		
Jan-00		
Feb-00		
Mar-00		
Apr-00		
May-00		
Jun-00		
Jul-00		
Aug-00		
Sep-00	Test Rev.	
Oct-00		
Nov-00		
Dec-00		
Jan-01		
Feb-01		
Mar-01		
Apr-01		
May-01		
Jun-01		
Jul-01		
Aug-01	Fab. Protos.	
Sep-01		
Oct-01		
Nov-01		
Dec-01		
Jan-02		
Feb-02		
Mar-02		
Apr-02		
May-02		
Jun-02		
Jul-02		
Aug-02	FDR