

Attachment Number C to the
Memorandum of Understanding (LIGO-M950060-A-M)
between the
Stanford Advanced Gravitational Wave Interferometry Group
and the
Laser Interferometer Gravitational Wave Observatory (LIGO) Laboratory
February 15, 2003

This Attachment to the Memorandum of Understanding LIGO-M950060-A-M covers the role of the Stanford Advanced Gravitational Wave Interferometry Group (Stanford Group) as a Charter Member of the LIGO Scientific Collaboration (LSC) and a member of the Lasers/Optics Development Group (LODG). The period of performance for the activities in this Attachment is from **February 15, 2003 to August 15, 2003**. This period may be modified by agreement to a revision of this Attachment.

1. LIGO Scientific Collaboration - The LIGO Scientific Collaboration is organized as a separate organization from the LIGO Laboratory. It includes scientists from the LIGO Laboratory, and those from collaborating institutions, and has its own leadership and governance. The Collaboration will ensure equal scientific opportunity for individual participants and institutions. It will organize the research, publications, and all other scientific activities. The Collaboration will report to the Laboratory Directorate for final approval of its research program, technical work, observational physics publications, and talks announcing new observations and physics results. This will be done through regular reports to the Directorate and its PAC.
2. Charter Membership - An initial period for formation of the Charter group of institutions in the LIGO Scientific Collaboration commenced on March 1, 1997 and ended following the first full meeting of the Collaboration at which the Collaboration Council assumed its role.

Following the charter period proposals will be evaluated through the Collaboration Council. With Collaboration approval, an MOU with the LIGO Laboratory, including Attachments defining specific work, will be required for any participating institutions.

3. This document is an agreement between the Stanford Group and the LIGO Laboratory concerning the activities of the Stanford Group as a Collaborating Institution in the LIGO Scientific Collaboration (LSC) and in the Lasers/Optics Development Group (LODG), and as indicated in Item No. 8 below.
4. Lasers/Optics Development Group - The Lasers/Optics Development Group (LODG) is the scientific collaboration for defining and developing future high power lasers and required improvements in optics for use in advanced subsystems for the initial LIGO interferometers

or in entirely new advanced interferometers. A specific Attachment will define the roles and responsibilities of groups in this development group. Members of this group will normally be authors in publications reporting the work of the group and will normally be eligible to participate in data runs and science beyond the LIGO I data run.

5. Report of Progress - The Stanford Group will provide a status report on its activities in support of LIGO every six months. The report will consist of: a) a summary status on research by topic as indicated item No. 8 below including progress against the milestones if any, significant accomplishments such as new insights/discoveries or publications, issues of concern if any, and an indication of invested time, b) updated List of Collaborators, and c) a plan of activities for the succeeding six-monthly period. The report will be due one month before the close of the period of performance under the Attachment in question.
6. Term of Membership - The membership will be renewed every six months upon evidence of satisfactory performance of agreed upon duties.

The Galileo group coordinates are included in Attachment Z to the Memorandum of Understanding LIGO-M950060-A-M.

7. Intellectual Property Rights - The rights to intellectual property developed under this Attachment will be subject to the National Science Foundation Grant Policy as indicated in Section 730, Intellectual Property.
8. During the period from **February 15, 2003 through August 15, 2003**: Professors Robert L. Byer, Martin M. Fejer; and James S. Harris; Senior Research Associate Roger Route; Part-time employees Alex Alexandrovski and Volodymyr Kondilenko; and Graduate Students David Jackrel, Shailendhar Saraf and Supriyo Sinha will work on high power optical amplifiers and their noise when saturated, adaptive optics for spatial mode control, a Gaussian to super Gaussian beam converter to improve the efficiency of the optical amplifier, optical absorption losses in sapphire and fused silica, and high power photodiodes. The Stanford group will:
 - a) Characterize 100W output beam from 2 MOPA stages using existing slabs in the high power laser lab;

We have achieved 100 W at the output of our MOPA chain. We will have to characterize the mode content and noise content of this beam. This level of power is achieved by triple passing an edge-pumped slab to bring the output from 20 W to 35 W. The 35 W beam is then double passed (using angular multiplexing) in an end-pumped slab to achieve 104 W. We will attenuate this beam and pass it through a mode-cleaner to measure the mode-content. We will have to build up locking electronics for our mode-cleaner to accomplish this. We will also determine the amplitude and frequency noise of the output. These numbers will then be compared to theory that we are in the process of developing on saturated slab amplifiers.
 - b) Prepare experimental setup for the 200W experiment;

Once the 100 W beam is fully characterized, we will turn our attention to obtaining a 200 W beam that meets the specifications of Advanced LIGO. Our plan is to take the 20 W beam

from the Lightwave Amplifier and double-pass it through two end-pumped slabs. The first slab will likely be pumped with a bundle of 30 W fiber coupled laser diodes. The final end-pumped slab will be pumped with the Laserline diodes at full power (600 W) to achieve maximum output power. We are also in the process of investigating polishing and coating techniques for the end-pumped slabs that both maximize pump coupling to the doped region and prevent parasitic oscillations.

c) Further develop phased array concepts;

Experiments involving super-mode generation from cold cavities for subsequent amplification in slabs will be continued. Phased gratings for this purpose will either be fabricated or purchased from an external vendor.

d) Implement superior control algorithms to increase the closed loop bandwidth of the adaptive optics system;

Preliminary measurements indicate that the 100 W beam may not require adaptive optics but it is very possible that the 200 W beam may require active wavefront compensation to maximize power in the TEM₀₀ mode.

e) Test all-silicon deformable mirror architecture to permit scaling to much higher powers;

f) Investigate to use of fiber pre-amplifiers in the early stages of the MOPA chain;

The high gains and stability of fiber amplifiers make them an attractive choice for a project such as advanced LIGO that requires both high power and high reliability. We will investigate the possibility of seeding high power double-clad fiber amplifiers with an NPRO to obtain 100 W of polarized, single-frequency output.

g) Continue making Photothermal Common-Path Interferometry (PCI) measurements of absorption losses in sapphire optics;

Volodymyr Kondilenko will continue to study post-growth heat-treatment processing on the residual optical absorption in HEM-grown sapphire crystals. We will continue a series of high temperature heat-treatment studies (to 1600° C) under controlled atmospheres using high purity, high density alumina atmosphere control components.

h) Continue the measurement of optical absorption losses in coated fused silica optics produced at MLD Technologies in a collaborative study with LIGO aimed at optimizing MLD's coating deposition and subsequent heat-treatment parameters; and

j) Continue the development of high power photodiodes.

Photodiode development for the next six-month period will be focused on fabricating high efficiency devices with thinned substrates using the newly designed process. Procedures need to be developed to mount the diodes to the aluminum nitride heat sink while preserving the electronic properties of the passivated junction. The junction will be protected using either a polyimide encapsulation layer or an insulating but thermally conductive low-viscosity epoxy, and flip-chip bonded to the ceramic heat sink via an indium to gold all-metal bond. The heat sink will provide mechanical support for the devices which will allow the highly doped GaAs

substrate to be thinned to below 50-microns. Once thinned and polished, a silicon nitride anti-reflection coating will be deposited by low-temperature evaporation. The thinned substrate will have sufficiently low free-carrier absorption, enabling the efficiencies of these devices to surpass 90%. A lower doped substrate, with carrier concentrations of $5 \times 10^{17} \text{cm}^{-3}$ instead of $3 \times 10^{18} \text{cm}^{-3}$, will also be used on some diodes, which will create detectors with efficiencies that are higher still. The DC and RF characteristics of the resulting devices will then be tested at Stanford using the 700mW NPRO set-up and other multi-Watt laser sources. Diodes will also be sent to MIT to serve as the high-power detector in the LASTI program, which requires a photodiode that can handle 300mA of photocurrent in order to keep the electronic noise component below the shot noise limit in their system.

9. As part of the research collaboration under this agreement the LIGO Laboratory will share, as requested and appropriate, LIGO data of relevance to the research focus in Item No. 8 above.
10. The research effort pursuant to this Attachment C will be coordinated by Roger Route and Gary Sanders on behalf of Stanford Group and the LIGO Laboratory, respectively.
11. Resource Sharing: The LIGO Laboratory will contribute resources including allocation of appropriate scientific and engineering personnel, research facilities and funding in support of the effort in Item No. 8, as indicated below.
 - a) Provide accommodations for Stanford Group investigators while on LIGO research assignment at Caltech, and/or LIGO sites.
 - b) Provide on loan a 10W Laser to be used in conjunction with the Stanford edge pumped slab laser for testing optical components at high power.

Approved:

Barry Barish
LIGO Laboratory Director

Date

Robert L. Byer
Principal Investigator

Date