LSC Six-Month Progress Report

Organization Stanford Advanced Gravitational Wave Interferometry Group
Report Date February 15, 2003

Attachment C - the Lasers and Optics Development Group
For the period August 2002 to February 2003

Lasers and Optics (R. Byer, M. Fejer, S. Saraf, S. Sinha)

a) We placed an end-pumped slab at the end of the MOPA chain. This slab was driven by approximately 32 W of TEM_{00} power which was provided by the LIGO laser followed by the Lightwave Electronics amplifier followed by the first edge-pumped slab. A single pass of the end-pumped slab yielded over 70 W of output power. The beam was carefully measured at 65 W to determine its mode content and its amplitude and frequency noise characteristics. To determine the mode content of the laser beam, the beam was attenuated and passed through a mode cleaner. It was determined that 74% of the output was in the TEM_{00} mode (better mode-matching could have yielded a slightly larger figure). Furthermore, over a period of 10 seconds, the power of the laser fluctuated only 2%. The intensity noise spectrum had values of approximately 10^{-6}/? Hz at 1 kHz and 10^{-8}/? Hz at 10 MHz.

However, the end-pumped slab had to be pumped with over 400 W to achieve these output powers, which results in a much lower efficiency than expected from theory. Upon further investigation, it was discovered that the unpolished faces of the slab (which were purposely roughened to eliminate parasitics) were scattering away a large fraction of the pump light before it could reach the doped region. We are currently investigating polishing and coating techniques to maximize pump confinement while avoiding parasitic oscillations.

We have also double passed the end-pumped slab using angular multiplexing to achieve 104 W of output power. In the near future, we will measure the mode content of this beam.

b) We continued with the development of the 200 W system. This power level will be achieved by removing the edge-pumped slab amplifier and replacing it with a double-passed end-pumped slab to bring us up to the 60 W level. A second end-pumped slab should bring us up to 200 W (after angular multiplexing) with about 600 W of pump power. We have assembled a second end-pumped laser head for this purpose. We also plan on measuring the thermal lens of the end-pumped slab with a Hartmann wavefront sensor to determine what cylindrical lenses will be required for thermal lens compensation.

c) Investigations of phased arrays as a means of power extraction from wide aspect ratio slabs was continued. Concepts such as super-mode generation in cold cavities and subsequent amplification through slab lasers are continuing to be studied. Adaptive optics were integrated into these studies for phase control of the elements of the array for wavefront correction and far-field steering. Early prototypes of segmented mirrors being designed for another program were studied to determine if they could be employed to control phase in the supercavity.

d) We began performing preliminary investigations on the use of fiber amplifiers as pre-amplifiers in the MOPA chain. We are in the process of coding a simulation program for high power fiber amplifiers which will accurately model ASE, non-linear effects and thermal effects in the fiber.

Optical Materials (V. Kondilenko, A. Alexandrovski, R. Route and M. Fejer)

e) Optical absorption in sapphire crystals

Volodymyr Kondilenko has continued to carry out optical absorption measurements on Crystal Systems' sapphire crystals. Most display bulk optical absorption at 1064 nm in the range of 40-60 ppm/cm. In past intervals, we worked with CSI to determine the influence of feed stock and post-growth thermal processing (heat-treatment) on 1064 nm residual absorption. Spatial distributions as well as absolute levels of optical absorption were compared with the segregation behavior of the known principal impurities in sapphire in an attempt to determine if any correlate with 1064 nm residual absorption. Impurity concentrations of likely "suspects" such as Ti, Fe, Mo, Cr, and Si are almost always present in the range of a few ppm atomic, which is near the limit of detection and which makes it difficult to draw firm conclusions.

Localized areas in one specimen, 8-T, were found to be in the range of 10-25 ppm/cm, which is within the Advanced LIGO spec. Sharp boundaries between these regions and adjacent regions having substantially high absorption indicated that strong melt segregation occurs and that it will be important to understand and control this effect. We prepared specimens on both sides of these sharp boundaries and are in the process of microchemical analysis in order to determine if trace impurities are playing a major role in limiting the average baseline absorption in CSI sapphire crystals to not much under the 40-60 ppm/cm range.

Initial annealing studies suggested the oxidation state of these impurities and/or vacancies on the aluminum or oxygen sub-lattice have an affect on residual absorption at 1064 nm. Improvements in optical properties (absorption < 25 ppm/cm at 1064 nm and only limited scatter in the bulk) were achieved by annealing at intermediate temperatures for extended periods in air. However, annealing at higher temperatures in air was clearly detrimental. We have been focusing on intermediate temperature heat treatment processing under inert/reducing conditions. It has recently emerged that under intermediate temperature annealing, the cooling rate has a strong effect on the optical absorption after the annealing procedure, with faster cooling rates yielding lower absorption losses than slower cooling rates. These studies have been promising and will be continued.

f) Absorption in optical coatings

The PCI technique has also been used to carry out absorption studies on optical coatings on single crystal sapphire and fused silica windows. This work is being carried out in collaboration with LIGO and MLD Technologies in a systematic comparison of multi-layer antireflection coatings composed of Nb_2O_5/SiO_2, Ta_2O_5/SiO_2, ZrO_2/SiO_2, Ta_2O_5/Al_2O_3, and SiO_2/Al_2O_3 on fused silica windows.

High power photodiode development (D. Jackrel, J. Harris, R. Byer, M. Fejer)

g) Photodiode development

A new process has been developed which incorporates a thinned substrate into our rear-illuminated photodiode design in order to obtain high efficiency devices. A new set of InGaAs devices have been processed using a passivating ammonium sulfide soak that exhibit breakdown voltages beyond –30V prior to mounting. An encapsulation procedure is currently being investigated that will protect the passivated junction and allow these devices to be flip-chip indium bonded to a ceramic aluminum nitride heat sink. Once the diodes are mounted they can be thinned to less than 50-microns, which will allow the detectors to achieve external quantum efficiencies of over 90%. Thinning the substrate is done to effectively lower the amount of parasitic free-carrier absorption in this layer. If a slightly lower doped substrate were to be used (i.e. $5e17cm^{-3}$ instead of $3e18cm^{-3}$) the absorption losses would be even further reduced and efficiencies of better than 95% may be achievable, although higher efficiency is traded for slightly larger series resistance.

The masks for this new process have been designed to fabricate devices ranging from 150-microns to 4.5mm in diameter, which will permit the simultaneous manufacture of each type of photodiode that Advanced LIGO will require. The largest of these devices has been designed to absorb over 1W of optical power without saturating if biased at –25V and will be used for power stabilization. The smaller diodes will saturate at lower power levels but will have increased response speed. These devices are to be used for the gravitational wave channel and for the high-speed RF detection in the length sensing and control systems. The RF diodes may be required to detect more than 100mW of optical power at up to 200MHz modulation frequency. One of our mid-sized photodiodes, 1.5mm in diameter, will be able to absorb over 100mW of optical power without saturating but will have a 3-dB bandwidth of only 30MHz. However, simulations of a tuned resonating detection circuit using an inductor in parallel with such a device have shown that sufficiently high impedances should be achievable at 200MHz. This will enable efficient detection in a bandwidth of a few MHz around 200MHz while keeping the electronic noise of the detection circuitry well below the imposed shot noise limit.