NOAO Annual Management Report
Adaptive Optics Development Program (AODP)

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Report for period April 1, 2008 to March 31, 2009
Management Activities and Findings

CARA
"Development of the Next Generation Optical Detectors for Wavefront Sensing"
The project has been granted a further 1 year no-cost extension for the effort to end on 12/31/09. The phase 2 (polar coordinate detector prototype) design is completed and awaiting the availability of wafer run for fabrication.

Since the last report the project has been working on two major areas, development of a collaboration to fund a dedicated wafer run to improve the project's control over the fabrication process and schedule, and the development of a larger version of the 160 x 160 pixel phase 1 device completed earlier in this program. The larger device will be used for the natural guide star (NGS) wavefront sensor on the early light AO system of the Thirty Meter Telescope (TMT). It is also of interest for other AO applications including the Next Generation AO system project at the W. M. Keck Observatory, and for applications in the imaging of cellular processes using low light high frame rate techniques such as green fluorescence imaging.

A collaboration has been developed with Robert Johnson of the Starfire Optical Range (SOR) at Kirtland Air Force Base in Albuquerque, NM. This collaboration on the development of advanced high speed CCDs for AO and imaging will allow the project to share the cost of a dedicated wafer run at MIT/LL to fabricate the phase 2 device (polar coordinate detector prototype), and also allow the design and fabrication of a larger version of the CCID-56. The larger device will have 256 x 256 pixels and 32 or 64 readout ports. A new, larger (131 pin) hermetic package with integral two stage thermoelectric cooler is also being designed for this device and for a 1024 x 1024 pixel imager for SOR.

The shared wafer run consists of 12 wafers carrying the following device designs:

1. 160 x 160 pixel adaptive optics (AO) imagers (CCID-56): split frame transfer, 21 µm pixels, 20 video outputs, planar JFET output amplifier, and possibly 2 stage output amplifiers. Revisions to design will be made to change to a two phase serial register, add a dump drain on the other side of the serial register, add a summing gate and possible changes to metallization of the output structure, and the possible addition of a second output gate.
2. 256 x 256 pixel AO imagers: 1500 Hz frame rate, split frame transfer, 18 to 21 µm pixels, 32 or 64 video outputs, 2 stage planar JFET output amplifiers.
3. 1024 x 1024 imager: 70 Hz frame rate, 16 µm pixels, 8 to 16 video outputs, 2 stage planar JFET output amplifiers.
4. Polar Coordinate Detector Prototype: 30 x 30 subaperture prototype of the polar coordinate detector, 724 active subapertures, 32 video outputs, 2 stage planar JFET output amplifiers, 10 µm pixels.

The wafer run will include process splits to allow testing of the optimal doping for the planar JFET, and will result in between 3 and 6 wafers for each split. All splits are expected to result in good devices, but
one split may provide a more optimal responsiveness and therefore better read noise performance from the planar JFET.

All wafers will be completed to a frontside illumination state, and selected wafers will be processed for backside illumination and the wafer probe tested. Selected devices will then be packaged for further testing and end use applications.

The design work for the 256 \times 256 and 1024 \times 1024 imagers will start in June 2009, and the wafer run is expected to start in October 2009. Delivery of back illumination processed parts will be in June 2010. Financial support for the 256 \times 256 design will be shared by CARA, the TMT project, and possibly a third government agency in the health sciences field. Financial support for the dedicated wafer run will be shared by CARA, the TMT project, SOR, and possibly a third government agency in the health sciences field.

**Lawrence Livermore National Labs**  
**“Pulsed Fiber Laser for Guide Stars”**  
This project is continuing with an additional no-cost extension through September 2009. The work is now being funded through CfAO at UCSC and a final report will be submitted to the AODP when work is complete. Unexpected delays and movement of the project to a new lab delayed progress. The work is now on schedule to be completed in 2009.

Packaging of the system is proceeding well:  
Have achieved 4.6W at 589nm in essentially CW format  
Have fixed the 1583nm final amplifier problem and produced stable output at the required power level  
The 938nm fiber laser has been repackaged and turns on repeatedly with little or no warm-up time.  
Still need to fix the 938nm Nd fiber efficiency problem. Problem has been identified and will be fixed in 2009.  
New 938nm passive fibers are on order and a new 1583 Er fiber is also on order.  
Need to demonstrate the system at a slower repetition rate.

The system should be fully functional and meet the original AODP specifications in 2009. The current plan is to move the final laser system to the Lick Observatory on Mount Hamilton in FY2010 as part of the CfAO ViLLaGes experiment.

**Lockheed Martin Coherent Technology (LMCT)**  
**“Compact Modular Scalable Versatile LGS Architecture for 8-100 m Telescopes”**  
This project is on schedule to complete in September 2009. All funds have been received by LMCT. During the past year, LMCT completed the phase II development and began phase III which was to disassemble the system from the two 4x6 foot optical tables and redesign and repackage into one 4x6 foot table which could be transported to an observatory for testing. Additional funding will be required to ship and set up the system at an observatory.  
The goal of Phase II of the program was to extract 100 W and 70 W from the 1064 nm and 1319 nm IR sub-systems, respectively. Based on a 31\% conversion efficiency in the non-linear stage, 50 W 589 nm output would then be expected.

The results from three different formats are as follows:

<table>
<thead>
<tr>
<th>Format</th>
<th>CW</th>
<th>MCAO</th>
<th>ELT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1064 nm</td>
<td>160W</td>
<td>160W</td>
<td>160W</td>
</tr>
</tbody>
</table>
There was concern that the low duty cycle of the pulsed format (especially the ELT format with a 5% duty cycle) would cause a significant loss in the average power. However, the higher energy input pulses more efficiently sweep out the available gain of the waveguide amplifiers, thus compensating for the loss of power realized by chopping the beam at low energy levels. Due to the higher cross-section of 1064 nm in YAG, amplification for the energy is more efficient, resulting in higher output energy levels than in the 1319 sub-system.

Several weeks were spent optimizing and stabilizing the IR beams in preparation for SFG of 589 nm through a single PPSLT crystal. The system was baselined using four different PPSLT crystals. The results as follows are based upon using one fourth of the available IR power to generate the 589 nm result.

<table>
<thead>
<tr>
<th>1064 nm</th>
<th>1319 nm</th>
<th>589 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW 34W</td>
<td>MCAO 40W</td>
<td>ELT 40W</td>
</tr>
<tr>
<td>28W 20W</td>
<td>18W</td>
<td></td>
</tr>
<tr>
<td>7.7W 8.5W</td>
<td>7.5W</td>
<td></td>
</tr>
</tbody>
</table>

The last line shows the total realized 589 nm energy from 4 separate PPSLT crystals. The bandwidth (BW) of the 589 nm beam was measured at different stages in the subsystem. The BW of the beam is below the resolution of the Fabry-Perot interferometer available, or less than 10 MHz. Greater conversion efficiency was expected through the PPSLT crystal, but it is believed that the inefficiency is due to two sources:

1. Beam jitter in the 1319 nm sub-system caused by polarization jitter in the NPRO fiber. This results in power fluctuations after the clean-up polarizer which causes thermal beam steering in the Lightboxes.
2. Diffraction effects caused by interaction of the input beam with the sides of the waveguides.

In order to remedy these two effects, the fiber will be removed from the 1319 nm NPRO and run free-space as is currently done in the 1064 nm NPRO. This will have the added benefit of increased output power from the NPRO. Wider waveguide amplifiers for the last amplifier stages in both legs will allow pumping a larger area of the gain material without suffering diffraction effects. A list of other proposed improvements is below which will all be implemented on current contract funds.

1. 4-pass 1319 nm Power Amp #1 to get nearer to Isat – 25% increase in extraction
2. Double-end pump 1319 nm Power Amp #3 (or add 4th Amp)
3. Replace 1319 nm mirrors with better 1064 AR coating to reduce ASE / parasitic promulgation
4. Use cylindrical optics to decouple guided & unguided for improved BQ
5. Relay image from NPRO through SFG crystal for improvement in BQ
6. Use in-house waveguide mounts for improved thermal control and beam launching (need 2 more).
7. Manifold for cooling system for increased reliability, stability, and safety
8. Interlock box for system safety
The Phase III effort began in late Spring 2009. The detailed optical design was successfully completed and implemented into a new opto-mechanical layout for a single 4x6 foot table. Re-build of the 1064nm MOPA system (NPRO + preamp + two waveguide amplifiers) commenced according to the new design, and average output power of 124W (MCAO pulsed) exceeded the planned exit criteria (75W). For the new 1319nm front end and pre-amp design, the NPRO laser was modified by JDSU to remove the PM fiber and boost the output power. The front-end build with the lightbox-preamp has been completed, with average output power of 310mW (MCAO pulsed) which exceeded the planned exit criteria (250mW).

During the re-work of the waveguide amplifiers for the 1319nm MOPA system (NPRO + preamp + four waveguide amplifiers), one was discovered to be delaminated, and another incurred some coating damage and had to be set aside as a marginal spare. Though the program was carrying a risk due to lack of spare 1319nm waveguides, the loss of two waveguides has presented a minor setback. To alleviate the cost and schedule problems that would be presented with the acquisition of new parts, a scrapped, full Talbot length, 1064nm waveguide was found that could be re-worked into two ½ Talbot 1319nm waveguides at an expedited cost of $17.5k. The purchase order and waveguide was supplied to PPC on June 25th, with delivery expected in 4 weeks. This presents the potential for a schedule slip of 2 weeks from the baseline plan (which had been carrying a schedule margin of 4 weeks).

To accommodate the portability goal of the AODP system, all support equipment has been standardized, electrically re-certified, and rack-mounted. The eight Affinity water chillers have been placed into two portable rack mounts, and the 8 diode power supplies, along with the MCAO pulse modulation controllers, in a third portable rack.

For 1319, the NPRO, eo-cell, isolator, and lightbox are up and running with the MCAO pulse. The first amp is in place, tested with a pump for flat-flat resonator performance. The beam from the lightbox has been formatted for the first amp. Next step is to add the optics to the table for the quad pass seeding of the first amp. PPC has the purchase order and waveguide material (delivered last Thursday June 25th) to cut, polish and recoat two ½ T 1319nm waveguides, delivery in 4 weeks (for amps 3 and 4). This effort should be near completion in early August 2009.