

CHAPTER 4

A PHOTOREFRACTIVE REGENERATIVE AMPLIFIER

4.1 Introduction

The autotuning filter of Chapter 2 extracts one principal component at a time. Extracting all the components requires cascading as many filters as there are signals at the input, minus one. The filter runs on a minimum of 3 mW of optical power supplied by the input signal-carrying beams. After the filter, the through beam is weaker since the ring extracts some of its energy and the gain crystal also absorbs nearly half of it. Current small laser sources—that easily fit in a briefcase for example—output up to a couple hundred milliwatts. This limits how many autotuning filters, or any other photorefractive circuit, may be daisy-chained before there is simply not enough optical power left to add a new one. Adding more laser sources is a complicated solution as our circuits rely on coherent beams: the added sources would have to be injection-locked. Amplification appears as a simpler solution in the long run.

This short chapter presents the first steps toward making photorefractive regenerative amplifiers. For the first amplifier, in hopefully a longer series, we chose to work on an amplifier that takes a multimode beam in and outputs a single mode beam with the same

temporal characteristics as the input beam. This amplifier could, for example, be added at the outputs of cascaded autotuning filters (the outputs that locally extract the largest principal component of their input space.) The same amplifier could not be inserted in between cascaded filters, as the spatial diversity needs to be preserved for the input of the following filter.

4.2 A photorefractive amplifier

4.2.1 Design issues

We chose to use a photorefractive ring oscillator to convert a multimode beam into a single mode beam. As mentioned in section 2.2, a ring oscillator pumped with photorefractive two-beam coupling transfers all of the temporal features of the input to the oscillating beam. This is true whether both or either of the input and ring beams are single mode or multimode. In the case of a single mode cavity, the photorefractive gratings adapt so that the diffracted input signal is always on resonance with the length of the loop [64]. Some of the photorefractive gain is sacrificed to induce the necessary phase shift if the signal is off resonance. In any case, this simple ring transforms a multimode beam into a single mode one. It does not overall provide gain: sampling the ring produces the output beam so the finite gain limits how much light can be taken out. To provide real gain we have two choices. One consists of adding a semiconductor laser amplifier in series with the single mode output beam. The second choice involves incorporating the semiconductor amplifier in the ring. It is a more elegant but also more complex solution. The challenge of inserting an amplifier in an adaptive resonator is that it will naturally tend to make the cavity lase at the frequency that yields the highest energy in the ring. This is due to the fact that the spontaneous emission of a semiconductor amplifier is equivalent to an optical broadband noise source. The design of a regenerative amplifier with a semiconductor laser diode in a photorefractive ring must therefore prevent the lasing and ensure that all the available gains serve to amplify a given signal.

We started our photorefractive amplifier experimental investigations with work necessary for both of the amplifier solutions mentioned above. We first learned how to pump a photorefractive ring resonator that was forced to be single mode. This constraint was

achieved by obliging the oscillating beam to couple in and out of a single mode fiber inserted in the loop. Second, we learned how to make a semiconductor laser diode amplifier since they are not commercially available. The following section provides the technical details about how to make the device.

4. 2. 2 Manufacturing a semi-conductor laser amplifier in a research laboratory

4. 2. 2. 1 The method

Conceptually, a traveling wave optical amplifier is simple. It is a laser diode gain medium through which an optical beam passes once. The first step to making a semiconductor amplifier is the acquisition of a semiconductor laser diode chip. In this world of cheap red laser pointers, it is surprisingly difficult to get small quantities of bare laser diode chips. Eventually the company Semiconductor Laser International sold us some uncoated, double heterostructured InGaAlP diodes, initially designed to emit at 655nm. The second manufacturing step consists of attaching the chips to a mount that allows us to deliver 200 mA of current to the chip and that acts as a heatsink. The third step is anti-reflection coating both facets of the chips.

4. 2. 2. 2 The technique

Mounting the chips

We used one of the industry's standard diode laser submounts called c-mounts with some slight modification. Figure 4.1 shows the modified c-mount. The top part of the mount is thinned down to be roughly the same thickness as the diode chip's length (about 500 microns.) This is so the full 30-degree cone of acceptance of the chips stays unobstructed on both sides. Our chips are designed to be single spatial mode laser sources

which leads to a smaller, $1 \times 3 \mu\text{m}$ -aperture than commercial multi-spatial modes power amplifiers which have 1×100 or $200 \mu\text{m}$ -apertures.

We glued the chips down on the mounts with very highly electrically and thermally conductive glue from Epoxy Technology (2 part epoxy, model # EPO-TEX H20E). We manipulate the chips with a Vacuum Parts Handling System from Techni-Tool. It is a pen-shaped tube, connected to a small vacuum pump on one end and fitted with a metal syringe tip on the other (plastic syringe tips turned out to pick up static electricity too well.). Miniature wood tweezers (carved out of a wood Q-tip stick) proved to be another useful tool to manipulate the chips. Once glued in place, the top metal sides of the chips are wedged-bonded to the ribbon-like electrode illustrated in Figure 4.1.

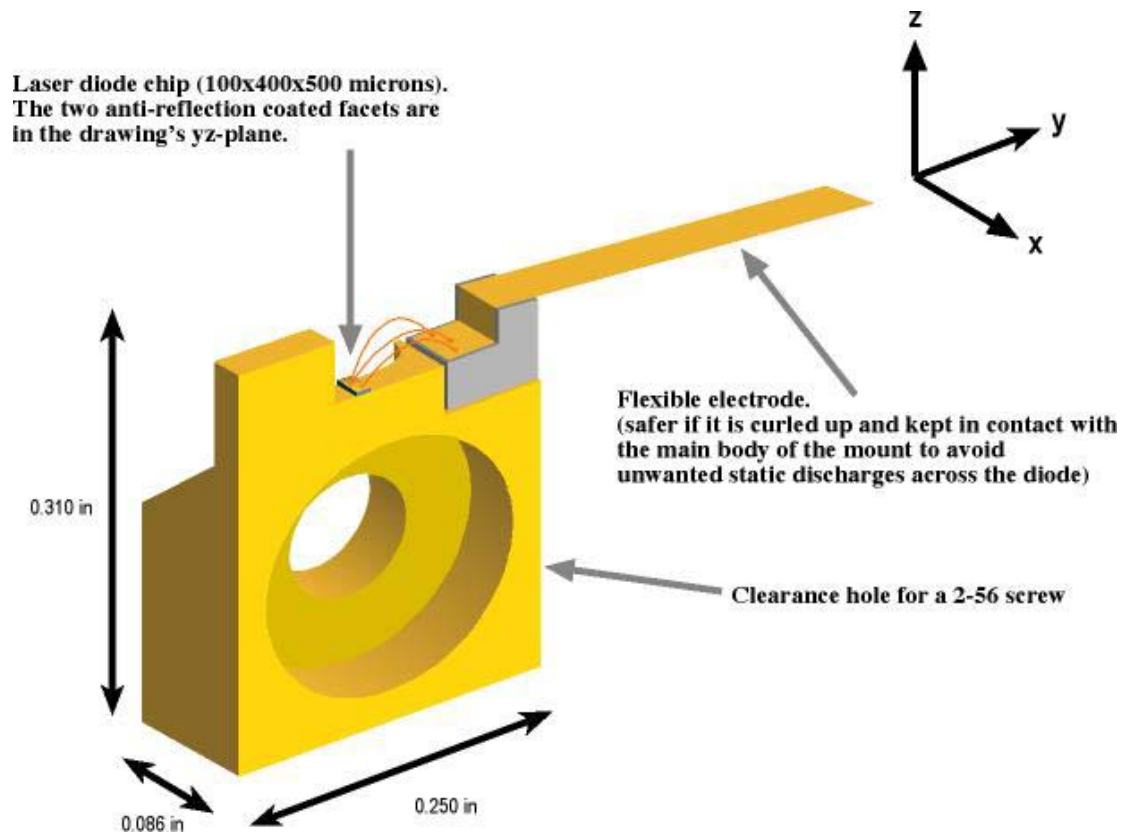


Figure 4.1 Schematic of the c-mount used to heatsink the semiconductor chip and also provide the electrodes necessary to supply the chip with current.

Coating the chips

InGaAlP has an index of refraction of 3.5 so that the facets of the chip produce natural 30% reflecting mirrors. These offer a resonating cavity to the spontaneously emitted light, imposing a lasing current threshold on the semiconductor amplifier. In addition, the presence of a cavity induces ripples on the wavelength dependent gain-curve that distort the amplification of a broad bandwidth signal. The better the anti-reflection coating and the smaller those ripples. Optical amplifiers became commercially viable when the reflections of their input and output facets were reduced to less than 0.01%.

The diodes' coatings were optimized by monitoring the laser output power versus the injection current during the coating process. We chose to deposit a single quarter-wavelength layer of HfO_2 by electron-beam evaporation. The diode's output-power-versus-current (PI) curve was continuously observed during the process: the diode was subject to a periodic ramp of current that was displayed on an oscilloscope along with the optical beam's power. When the lasing current threshold was crossed, the slope of the PI curve exhibited a sudden change. As the coating approached the optimal thickness, the lasing disappeared altogether. We then closely observed the peak power of the spontaneous emission decrease. The deposition process was stopped when the decrease-rate slowed down, which was sign that the light emission was at a minimum and about to increase again. Figure 4.2 shows the PI curves of a diode measured before coating and then after each facet has been coated. Reflection curves taken with an optical spectrum analyzer and microscope revealed the center wavelength and bandwidth of the coatings. We achieved less than 0.01% reflection over tens of nanometers.

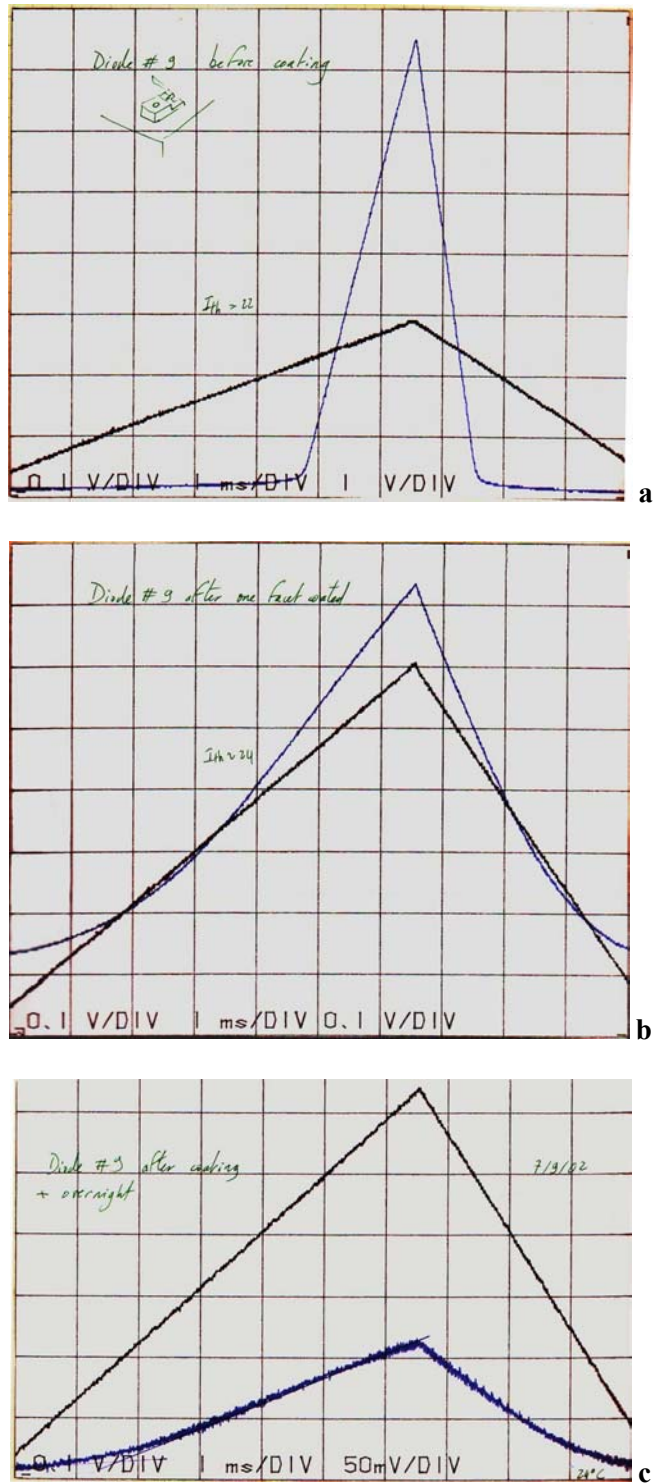


Figure 4.2. PI curves of a laser diode. The triangular black curves represent the current passing through the diode. Their vertical scale is 100 mV for 10 mA. The nonlinear blue curves represent the laser output power monitored by a photodetector placed in the vacuum chamber, taken a) before coating, ($I_{th} = 22$ mA), b) after coating one facet ($I_{th} = 33$ mA), and c) after coating both facets (lasing I_{th} not apparent below 65 mA).

The thickness of HfO_2 deposited was monitored through the resonant frequency of a piezo-electric crystal being coated alongside the chips. Unfortunately our calibration of the thickness deposited was not repeatable enough. The center frequency of the anti-reflection coating changed (over 100 nm) with nearly every run. The yield of usable diodes was low so we sacrificed performance for speed: we sent our diodes to be coated in bulk to a coating company (Spectrum Thin Films, NY.) The diodes were packaged so that the c-mounts were attached to a single metal “window frame” (both sides of the diodes had to be open for coating) and each had its electrodes shorted. The diodes survived the trip and came back with a good uniform coating for 655 nm.

4. 2. 2. 3 Results

The uncoated diode chips purchased from SLI were originally intended to become 35 mW laser diodes with 80 mA of current. The anti-reflection coated diode chips, pumped with 100 mA of current, amplified a 0.2 mW, 655 nm beam up to 20 mW. This is an unsaturated gain of 20 dB.

4.2.3 Immediate future work

The immediate next step will consist of integrating the c-mounted diode in a pre-aligned lens-diode-lens unit. Figure 4.3 shows the proposed design for the mechanical alignment of the unit with 5 degrees of freedom (the unnecessary 6th is the rotation around the diode's waveguide axis). The pre-aligned unit could then be inserted into any circuit where a diode amplifier needs to be tried out.

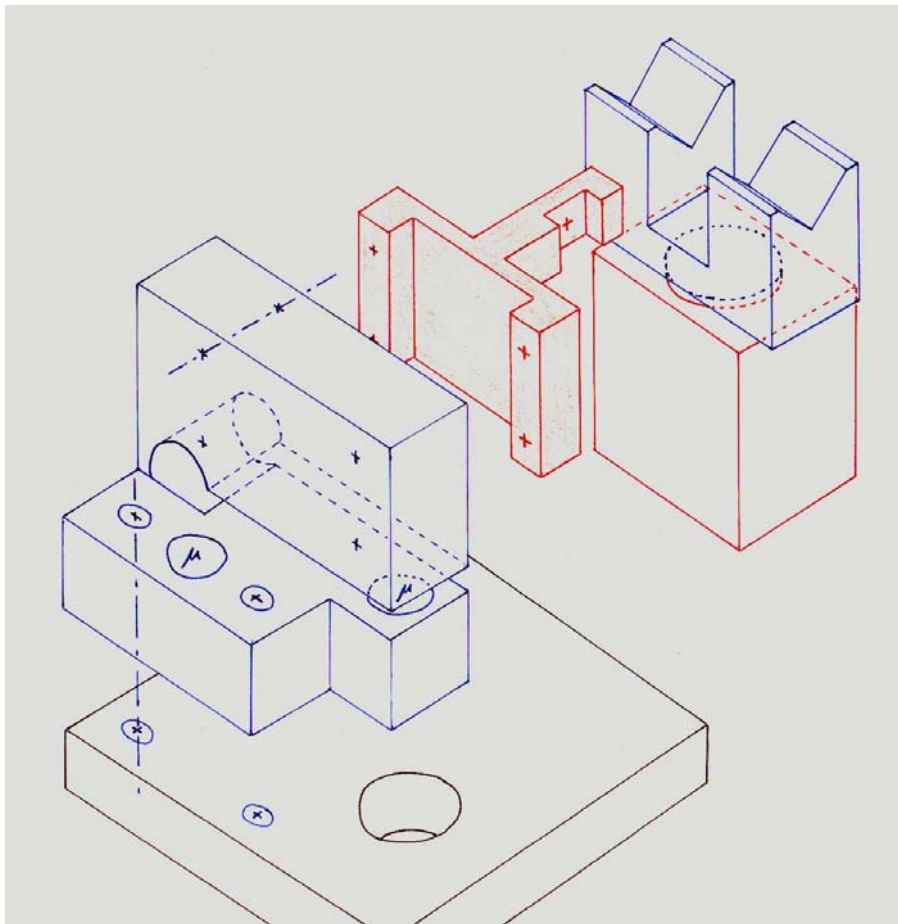


Figure 4.3. Proposed mechanical mount to align a lens, the diode amplifier and another lens.