High Power Monolithic Passively Modelocked Semiconductor Laser at 1550 nm Wavelength

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Abstract
In recent years, there has been a surging interest in generating ultrashort pulses from a monolithic, electrically pumped semiconductor laser. Modelocking the laser diodes usually produces pulses whose widths are on the order of a few pico-seconds. The drawback of a monolithic semiconductor laser is that it produces pulses whose energies do not usually exceed a few pico-joules. Using a slab coupled optical waveguide geometry laser, we have managed to increase the limit by an order of magnitude. Our lasers directly produce pulses with energies exceeding 40 pJ.

Summary of Research
Our group is investigating the generation of high energy ultrashort optical pulses from a semiconductor diode laser. The geometry that we are interested in is the slab couple optical waveguide laser. The structure makes it possible to increase the saturation energy which allows us to generate pulses whose energies are tens of pico-joules. The added advantage of this structure is that the laser produces a single transverse mode beam with large modal area (≈ 20 µm²).

Using MOCVD, epitaxial layers of InGaAsP are grown on an n-InP substrate. A 4 µm thick layer of InGaAsP serves as the mode guiding section. The active region which comprises of five 8 nm InGaAsP quantum wells is grown on top of this mode guiding layer. The active region is then covered by a 1 µm thick p-InP which allows us to make ohmic contacts for the laser on the top of the ridge (Figures 1, 2).

![Figure 1: Schematic of the cross-section of the laser.](image1)

![Figure 2: SEM of one of the facets of the fabricated lasers. The region marked by InGaAsP is the wave-guiding section which is 4 m thick. The section marked MQW region consists of five periods of InGaAsP based quantum wells and barriers.](image2)
The wafer was covered with a 300 nm SiO$_2$ film using the IPE PECVD tool. Waveguides were defined using standard optical lithography techniques. We used SPR 220-3.0 resist and exposed it in the GCA AutoStep 200. The pattern was transferred to the underlying oxide layer and after stripping the resist, the patterned oxide was used as etch mask for etching the semiconductor. Using a Cl$_2$/H$_2$/Ar recipe, the semiconductor was etched in an ICP tool. The ridge height of the waveguides was around 1.9 µm. The etch mask was removed and a fresh 280 nm layer of PECVD oxide was deposited. Again using optical lithography, we defined openings on the top of the waveguides from which we etched away the oxide using a CHF$_3$/O$_2$ RIE recipe. The Ti/Pt/Au ohmic contact was evaporated on top of the waveguides. The ohmic contact was defined using a bi-layer photoresist lift-off procedure. Once the ohmic contact was defined, the substrate was thinned down to a thickness of about 150 µm. A Ni/Ge/Au n-ohmic contact was evaporated on the back side. The sample was annealed at 400°C for 30 seconds.

The laser bars were cleaved to a length of about 9.0 mm. The bare semiconductor/air interface had 30% reflectivity. This was good enough to obtain lasing, but to increase the output power from one of the facets we evaporated three periods of Al$_2$O$_3$/Si to serve as a high reflection coating. The output facet is also coated with just one layer of Al$_2$O$_3$ in order to reduce the reflectivity to about 10%.

The laser bars were mounted on gold plated copper chuck using indium solder. To modelock the laser, the top ohmic contact was segmented and electrically isolated into two parts. The longer section served as the gain section and was forward biased. The shorter section was reverse biased and it is this section, which acts as the saturable absorber, which is the main pulse shaping agent. About 1.5 Amp of current was passed through the gain section. The reverse bias across the saturable absorber section was then gradually increased. At a reverse bias voltage between 1.5 V and 2.0 V (depending on the forward bias current), the laser modelocked. Increasing the reverse bias voltage beyond this point results in a decrease in the width of the pulse (Figure 3). The shortest pulse width measured via autocorrelation was just over 5 ps (Figure 4). The highest pulse energies though, were observed right around the reverse bias voltage where the laser modelocks. Increasing the reverse bias voltage leads to a decrease in the pulse energy. The highest pulse energy observed thus far was over 40 pJ.

References