#### ADVANCED UNDERGRADUATE LABORATORY

### **EXPERIMENT 43**

### FEMTOSECOND FIBRE-OPTIC LASER

Last paper revision: June 2005, by Jason Harlow Original write-up by Robin Marjoribanks, available on the web at http://www.physics.utoronto.ca/~photonic/wwwphotonics/

## Introduction

Much of the revolution in fibre-optic communications has been driven by new discoveries and inventions by optical physicists. New laser materials, and new designs and configurations, have created whole generations -- even new species -- of light sources, particularly since the early 1990s. Many of these developments have opened new technical possibilities and prospects for commercial application.

At the root of all this technical progress lies progress in understanding and discovery, much of it driven not by programmatic needs but by a pressing personal need to figure out how things fit together into a picture. This experiment is very well suited to that kind of curiosity and tinkering.

#### Simple lasers

Fibre lasers are among the simplest lasers: they don't have transverse modes, typically, and they're solidstate, with few adjustable parameters. In addition, they're made from components whose standards in uniformity and reliability have been established by the requirements of the telecommunications industry. At the same time, the optical nonlinearities of moderately intense ultrashort pulses (~100 fs) in these lasers make them an extremely rich place to discover fascinating and complex nonlinear physics. The experiments based on this laser will let you explore several regimes of nonlinear optical and laser physics.

#### Useful background

You'll find it an advantage, but not essential, to have already done the experiments on the He-Ne laser (including modelocking) and on fibre-optics (how they work as waveguides, including single-mode waveguides, and the transverse distribution of fields). A little more important is the acoustic-waveguide experiment in this same lab-room, which leads you through pulse spreading due to group-velocity dispersion. If you haven't done the experiments, it may be useful to read the experimental guide sheets.

Advanced or specialist students may be interested to read the review paper on ultrashort-pulse fibre lasers by Nelson *et al.* 1997. Excellent books include Derickson 1998, Agrawal 2001 and Boyd 1992; the first two are available through the equipment wicket, and the last is available in the Physics Library.

## Experiment

The first issue is your safety: the fibre laser has a power comparable to a small HeNe laser and poses no perceptible danger to your skin, etc. Its wavelength and power is also eye-safe under normal conditions, but the wavelength is not visible, for two reasons. This wavelength is stopped in the cornea or lens of the eye, and does not go to the retina. As is the case with many lab HeNe lasers, *you must not focus the beam to your eye* with a lens, like a microscope or telescope. When used with the fibre amplifier (advanced) the fibre laser is capable of 45 mW of output power, which is significant and can be dangerous to your eyes when operated in femtosecond mode and focused. There are no dangerous voltages in the laser. You are encouraged to learn about laser safety, through the University of Toronto and other laser safety sites.

To track the infrared laser beam, there is a small infrared-laser revealing card, which will show a faint orange spot, barely visible under room lights.

#### Safety of the Laser Equipment

The second issue is the laser's safety: there is very little you can do to damage anything in the equipment, but:

- you must not let the driver current to the diode pump-laser go beyond 650 mA; we have provided a current limit setting that will protect the device (a red light and alert beep, plus a maximum-current clamp), but please tell a lab technician immediately if you see any signs that someone has altered this safety setting.
- you must not **ever** reach **anything** into the plexiglass case protecting the laser. If anything falls through a hole, do not attempt to reach the item with a pencil or tape or anything else, and do not attempt to open the case. The glass fibre is protected, but is fairly fragile and will break if poked with a pen or other object. Call the lab technician, and they will recover the item safely.
- you must not put items (papers, pens, books, anything) on top of the plexiglass display case for the laser. It's not strong enough, can easily be scratched, and can be charged up with static electricity, which is dangerous to the diode-laser pump inside. This practice also leads to items dropping through the holes into the case (see point above).
- you must not run the diode pump-laser without the thermoelectric cooler running; if the voltmeter showing the pump-laser temperature reads very nearly 1.0 V, then all should be well
- you must be very careful about connecting different fibre-optic cables: there are cables in the lab with connectors which can be attached, but which will cause irreversible damage to the fibre. Beware especially the FC connectors which have green boots.

Here's how to turn on the laser:

- 1. Ensure that the 9VDC power supply to the thermoelectric cooler is plugged in at the wall, and connected to the laser. There should be a green indicator light (LED) showing that it is plugged in.
- 2. Turn on the digital multimeter connected to the fibre laser. This monitors a thermistor measuring the temperature of the 980nm diode pump laser. It should read about 1 volt at all times; if the value differs more than 10% from this, do not run the laser, and if it's already running, shut it down immediately.
- 3. Turn on the Tektronix TDS210 oscilloscope near the left side of the laser. You'll be looking eventually for a signal 50-200 mV, with pulses at about 25 MHz. Start with triggering "auto".
- 4. Turn on the bias supply voltage on the InGaAs photodetector attached to the oscilloscope
- 5. Turn on the main power push-button at the lower left of the diode laser controller. Near the middle of the panel is a selector that will let you cycle over four different settings for reading the controller and the pump-laser output. When turned on, the first value showing will be *I*-limit, the maximum current permitted to be sent to the pump. This supply is set for a current-limit of about 650 mA, which will prevent you from doing anything seriously wrong with the apparatus; **this setting must not be changed or complete destruction of the diode laser may result.**
- 6. Press the tactile membrane-switch at upper right, marked **Enable**. The pump laser is now on, and the driver current can be adjusted using the main knob. If you cycle through the display settings, you can monitor (in order): current limit, drive current, output power, and signal current from the built-in photodiode monitor.

The fibre laser will now be operational. The way in which it operates, and all its characteristics, depend on adjustments made to the pump power and to elements of the fibre laser itself.

## **Exercise 1: Measuring the slope efficiency in cw mode:**

First exercise: Measure the cw laser output power as a function of pump power

- 1. The orange fibre-optic cable (about 1 m long) from the laser output should be connected to the 50/50 optical splitter, into the common port. The two output ports should go to the photodetector on the TDS210 oscilloscope, and to the Optical Spectrum Analyzer (Ando).
- 2. Set the fibre laser to operate in "vanilla" cw mode, by loosening the stainless-steel thumbscrews on the pressure-plates of both polarization controllers, with your fingers. Do not unscrew them completely or they will fall off, which is annoying.
- 3. You should see a flat signal of about 50 mV on the oscilloscope. Pivot the upper-left polarization controller while watching the output power on the oscilloscope. You may find the fibre laser already modelocking, but as you unscrew the pressure-plate you will go to cw mode. If when you pivot the controller the power on the oscilloscope changes, then there is still stress-birefringence in the fibre -- carefully unscrew the thumbscrew a little further, until the oscilloscope signal is no longer sensitive to the pivoting of that plate
- 4. Repeat for the lower-right polarization controller.
- 5. Move the ouput fibre to the Exfo power meter. That meter has several settings for different types of laser -- you may have to press the button for "wavelength" to cycle among different pre-set setups, to get the setting for 1550 nm. With the pump laser drive current set around 600 mW, you should see 1-2 mW output.
- 6. Find the behaviour of the laser output power as a function of pump power. To track the diodelaser pump-power, you can use the built-in photodiode-monitor from the diode-laser driver, or you can use the calibration curve of drive current vs. pump-laser output, provided by JDS Uniphase, the manufacturer.
- 7. Plot your results (using Kaleidagraph on the lab computers, for example); find the functional relation between pump power and fibre-laser output power. Explain each part of your observations -- how do you understand the features of what you see? With the understanding that you have formed, always see if you can test your ideas by changing something.

**Variation:** the fibre-ring can have a measure of residual birefringence, from stresses of being coiled up. Try small amounts of pressure from the thumbscrew of the upper left polarization controller, and different pivot-positions, to see if you can compensate, and maximize the cw power of the fibre laser. Then repeat the power measurements -- do you expect to see a difference?

## **Exercise 2: Obtaining modelocking**

The femtosecond fibre laser Primer does a good job of sketching how mode locking works, and how to begin to make it modelock. In summary, you can:

- 1. Set the diode-laser driver current to 600mA.
- 2. As you monitor the cw power on the oscilloscope, gently begin to screw in the thumbscrew of the polarization controller, while also periodically pivoting the centre body. Initially, pivoting will not affect the laser cw power, but as the pressure plate begins to stress the glass fibre, you'll begin to see that the cw power is affected by the orientation of the pivoting section, rolling about the axis of the fibre. This is the best indicator of when the glass is being stressed, because even very sensitive fingers will not feel much.
- 3. After seeing the beginning of such an effect, one full turn of the pressure-screw is usually all that's needed.

- 4. It often happens that there is sufficient stress in the fibre (due to being gathered up into loops) to act as a second polarization waveplate. In that case, you will often get modelocking immediately after fiddling with the first polarization controller. It will appear on the oscilloscope as a train of pulses at about 25 MHz repetition rate (40 ns pulse-separation).
- 5. If adjusting the first polarization controller does not spontaneously produce modelocking, repeat the first step above for the second polarization controller, rightmost and closer to you than the first. When both polarization controllers affect the cw intensity, as they are pivoted, you are within one turn of the thumbscrews of a proper pressure. You have made them sufficiently birefringent.
- 6. You will find that the laser will modelock, or run cw, depending on the pivoting of the controllers -- that is, depending on the orientation of the stress-induced waveplate. Make modest, systematic changes to the pivoting of both controllers. On the small chance that this produces nothing, though the cw power rises and falls, try first using *less* pressure on the controllers (unscrew the thumbscrew slightly). If that fails, try a little more pressure than you had just now, before loosening.
- 7. When you have modelocking, turn on the Ando Optical Spectrum Analyzer (OSA), and see what the spectrum looks like. At its best, it can appear as a smooth near-Gaussian spectrum, with a width up to 40nm. More typically, it's fine if it's not quite smooth, and not quite Gaussian.
- 8. Starting with this 600mA drive current, and decreasing, repeat your earlier cw measurements of slope efficiency.

If you see other sorts of behaviour, you're quite welcome to explore settings of pump power, and settings of the polarization controller. Some very interesting things can happen! However, you should get the "standard" behaviour above before proceeding to the next exercise.

## **Exercise 3: Measuring pulse duration**

Start by reading about autocorrelation as a way to measure pulse duration for ultrafast laser pulses. The autocorrelator we have in the lab is described in detail in "Using the Interferometric Autocorrelator", which you should also read.

- 1. Use the moving-mirror configuration first.
- 2. Find the pulse duration of the pulses of any modelocked pulse you can output; use only the standard ~1m orange MetroCor fibre on the output, to start with.
- 3. While monitoring the autocorrelation "live" in real time, make changes to the polarization controllers, and see what happens to the output as you adjust them, particularly as you roll them over until the modelocking stops. Note any changes in pulsewidth, shape, or stability
- 4. Click the RUN/STOP button and estimate the autocorrelation width; from this find the pulse duration.

If you see other sorts of behaviour, you're quite welcome to explore settings of pump power, and settings of the polarization controller. Some very interesting things can happen! However, you should get the "standard" behaviour above before proceeding to the next exercise.

## **Exercise 4: Measuring fibre dispersion**

As in the acoustic-waveguide experiment, pulses will disperse in fibres, stretching longer and chirping as they propagate. Use different lengths of fibre, and measure the pulse duration at the output to figure out what the dispersion of the fibre is. Be careful and gentle with the fibre cables, since many of them

are hand-made and all of them are fragile with respect to scratches, crushing forces, and too-tight loops (no bends tighter than 50 mm diameter please!)

- 1. Use the moving-mirror configuration first.
- 2. Set the fibre laser up for stable operation with fairly short output pulse durations.
- 3. Keep the 1m orange (MetroCor) fibre cable still attached to the autocorrelator input, and add different lengths of different fibres between the fibre laser output connector and the permanent 1m orange fibre cable. The signals may change on the autocorrelator, but if you do not change the 1m orange fibre to the autocorrelator, you will not need to adjust the autocorrelator alignment (and it won't help).
- 4. After making several relatively quick assessments, and a plan for your measurements, switch to the long-timebase configuration of the autocorrelator. Make your first measurement the one of using just the original 1m orange MetroCor fibre.
- 5. Find pulse durations as a function of length of fibre, for each fibre; bear in mind that you will measure the intensity autocorrelation, not the fringes here (the fringes always show the coherence time, now!). explain what you see
- 6. Find the dispersion of each fibre, in units of  $[ps nm^{-1} m^{-1}]$  (i.e.,  $[ps/(nm \cdot m)]$ ).

## **Exercise 5: Advanced experiments**

If you've succeeded at the above experiments, you're welcome to try one or more of these advanced experiments. Discuss your goals, and your methods, with a knowledgeable TA or supervising professor, before you go too far.

- 1. effects of variable gain on pulse duration
- 2. Can the right fibre recompress a pulse that has been stretched by the gain above, to make a much more powerful femtosecond pulse?
- 3. multiple-pulse output of the fibre-laser: conditions for causing; effects on spectrum; effects on autocorrelation
- 4. encoding time-information (e.g., semiconductor reflectivity) on a frequency-chirped pulse and reading it out with a spectrograph (reference)
- 5. nonlinear optics

# References

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**For all references and many links, please see the web site of the** Photonics/Optics Teaching Laboratory at the Department of Physics at the University of Toronto:

# http://www.physics.utoronto.ca/~photonic/wwwphotonics/