Fiber Laser Pumped Optical Parametric Oscillator:

FPPO-1000

Product Manual

2012

.com

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Specifications and Overview

The FPO-1000 is a tunable, picosecond OPO pumped by a fiber laser. The system has three outputs:

- *Fiber Laser Pump*: up to 1W at 1064 nm, 6 ps pulses, 109 MHz, spectral width <10 cm^{-1}
- *OPO signal beam*: 250-500 mW, tunable from 740 to 1000 nm, 6 ps pulses, 109 MHz, spectral width <10 cm^{-1}
- *OPO idler beam*: 100-400 mW, tunable from 1150 to 1800 nm, 6 ps pulses, 109 MHz, spectral width <10 cm^{-1}

Shown below is a typical tuning curve for the OPO. The power level of the signal beam (blue) and idler beam (red) is shown as a function of wavelength.

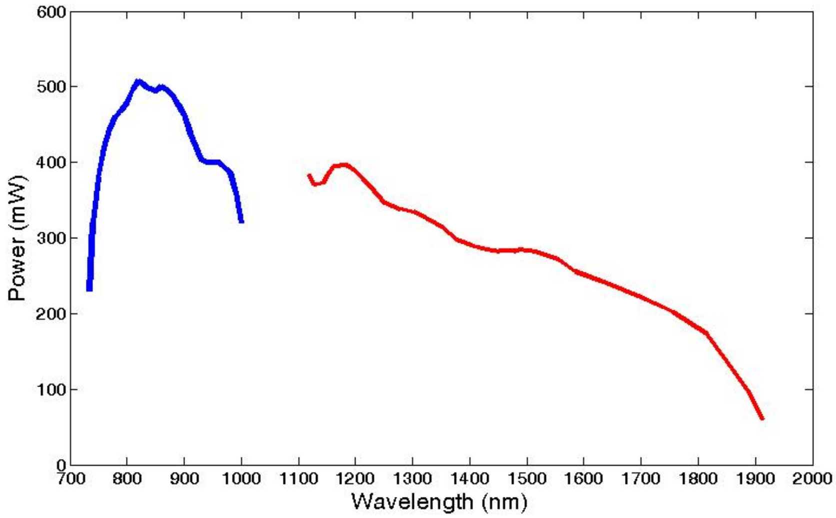

Figure 1. OPO tuning curve. Signal (blue) and idler (red) power levels as a function of wavelength.

The FPPO provides short (picosecond)pulses with narrow linewidths (<10 cm^{-1}). Shown below is a typical autocorrelation trace and pulse spectrum of the signal beam.

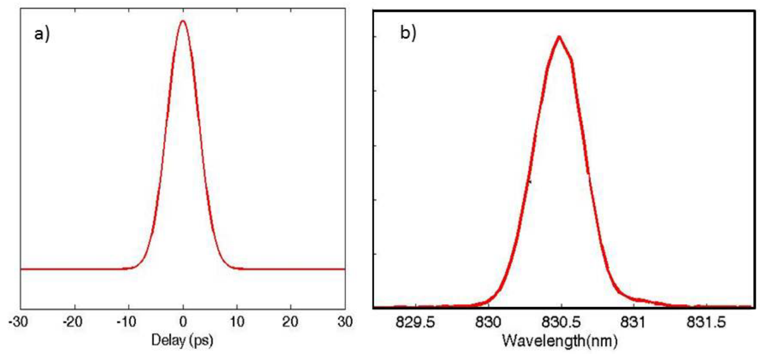

Figure 2. Typical autocorrelation (a) and spectrum (b) for the signal of the FPPO showing a pulse duration of 5 ps and a bandwidth of 0.5 nm at a center wavelength of 830.5 nm.

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General Layout of System

A block diagram showing the layout of the system is shown in figure 3 below. The fiber laser pump leads into a module that compresses the pulses to near the bandwidth limit. This module also contains optics that allows the user to control the power of the pump beam. After compression, the 1064 nm pump beam is doubled to 532 nm in the SHG module. The residual pump beam (>1W) is separated from the second harmonic beam with a dichroic mirror, and is available for use in experiments. The 532 nm beam is used to pump the OPO, which provides outputs for both signal and idler beams. The signal and idler are beams are created through a parametric process that splits a pump photon into a signal and idler pair. By conservation of energy, the wavelengths of the pump, signal and idler beams are related by:

$$\frac{1}{\lambda_{pump}} = \frac{1}{\lambda_{signal}} + \frac{1}{\lambda_{idler}}$$

Since the pump wavelength is a constant 532 nm, the relationship between signal and idler wavelengths is easily determined form the above equation.

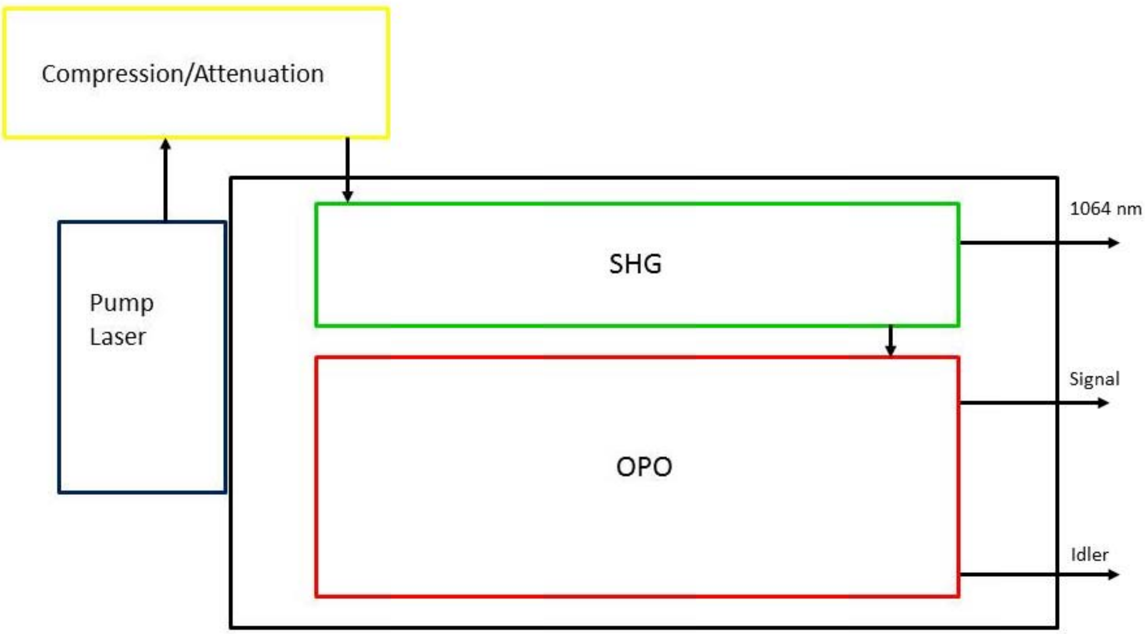

Figure 3. Layout of the OPO system consisting of Fiber Laser Pump, module for compression and attenuation, second harmonic generation module, and OPO cavity

Compression and Attenuation

External compression is used to compensate for residual chirp from the fiber laser. This compressor consists of a polarizing beamsplitter (PBS1), a quarter waveplate (QWP), and a chirped volume Bragg grating. Pulses from the laser are vertically polarizer and are reflected from PBS1. After passing through the QWP the beam is circularly polarized, and then is compressed after being reflected from the VBG. A second pass through the QWP changes the polarization to horizontal, and it is then transmitted through PBS1.

A variable attenuator consisting of a half waveplate (HWP) and polarizing beamsplitter (PBS2) is used to adjust the power of the beam for alignment purposes. Rotation of the HWP changes the polarization of the beam, allowing the vertical component to be reflected and the horizontal component to be transmitted by PBS2.

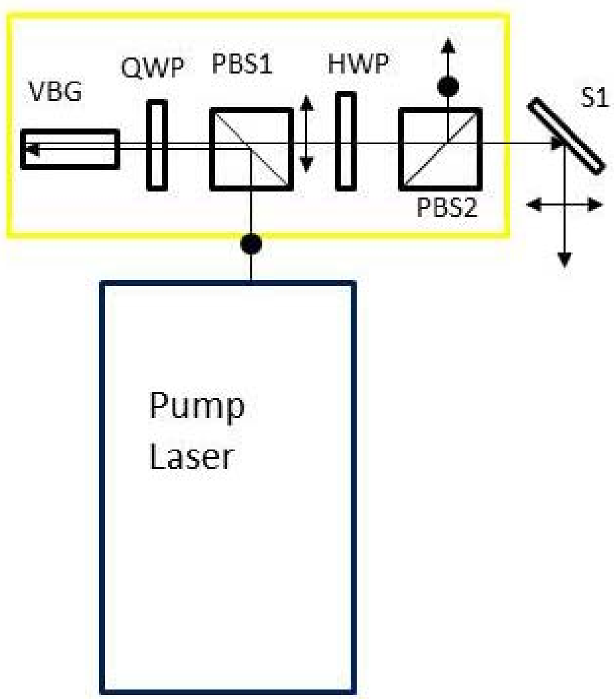

Figure 4. Compression and attenuation module. **VBG**: volume Bragg grating, **QWP**: quarter-wave plate, **PBS**: polarizing beam splitter, **HWP**: half-wave plate, **S1**: steering mirror

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Second Harmonic Generation

The second harmonic generation (SHG) section consist of two steering mirrors (S1 and S2), a focusing lens, a crystal in an oven (X1) , and a dichroic mirror (DCM). Approximately 5 W of power is present in the pump beam after compression, and this is focused into an LBO crystal to convert to 532 nm. The oven temperature is set to 148°C, which is optimized for type-I non-critically phase matched SHG. Approximately 2 W of 532 nm light is generated, which is polarized in the vertical direction. By using a dichroic mirror, which reflects 532 nm and transmits 1064 nm, the SHG beam is separated from the fundamental beam.

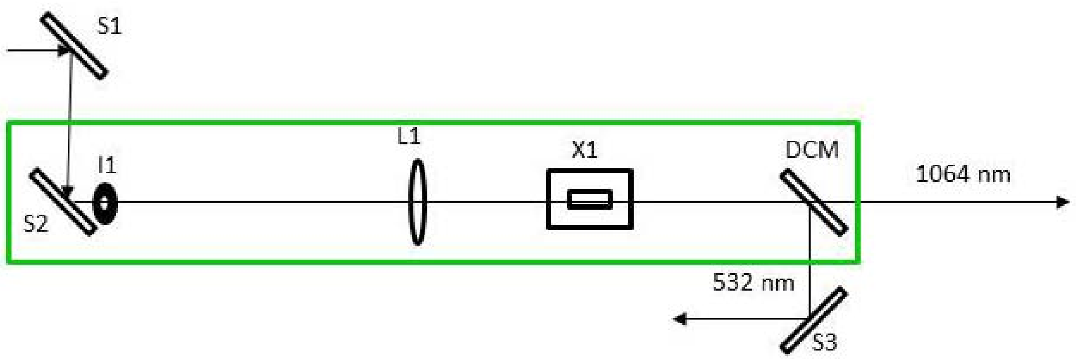

Figure 5. Second harmonic generation module. , **L**: lens, **S**: steering mirrors, **DCM**: dichroic mirror, **I**: iris, **X1**: LBO crystal in oven

OPO Cavity

The OPO is a linear cavity with end mirror M1, fold mirror M2, curved mirrors M3 and M4, and output coupler (OC). The 532 nm beam is focused into the LBO crystal (X2) with a telescope (L1 and L2). The cavity mirrors are highly transmissive for idler wavelengths, so the idler wave is coupled out of the cavity at M4. The signal beam is resonated in the cavity and exits at the output coupler. Tuning of signal wavelength is done with a combination of temperature tuning of the LBO crystal (X1), rotation of the birefringent plate, and adjusting the length of the cavity by translating M1. Signal and idler outputs are both polarized horizontally, and are filtered from residual 532 nm light by using filters F1 and F2.

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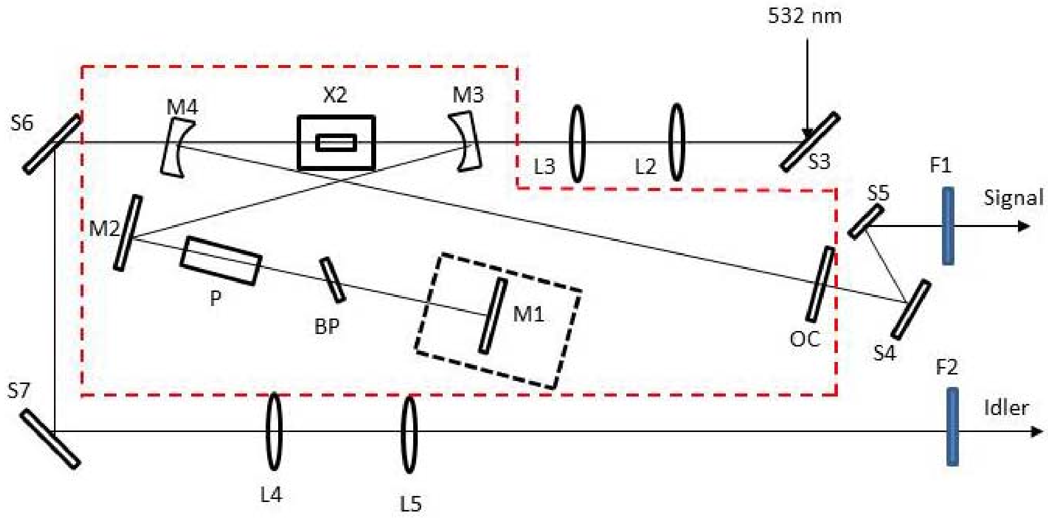

Figure 6. OPO cavity. **L2, L3**: lenses to focus 532 nm beam into crystal, **X2**: LBO crystal in oven, **L**: lens, **S**: steering mirrors, **M1**: OPO cavity end mirror on motorized translation stage, **M2**: OPO cavity folding mirror**, M3, M4**: curved mirrors, **OC**: output coupler, **P**: Brewster angle polarizer, **BP**: birefringent filter plate mounted in motorized rotation stage, , **F1, F2**: long pass filters, . **L4, L5**: lenses to collimate idler beam

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Getting Started

Pump Laser

Install the pump laser and software according to the manual. On the rear panel of the laser, turn on the master oscillator by pressing the “Oscillator On” button; the button will light up green when on. Next, enable the amplifier by turning the key switch to the “ON” position.

Please note, even with the key switch in the 0 position, there will be residual radiation emitted through the output optic. The power of the residual radiation is <30 mW, making the system a **Class 3B** laser. Avoid looking into the output optic and observe laser safety rules. Optical emission is completely switched off when the master source start button is switched off and the green LED is off.

When the emission indicator LED is on, the system is a Class 4 laser. Observe laser safety regulations and only operate the laser after you have familiarized yourself with its controls.

The amplifier level is controlled by “HyperTerminal” software on a computer connected to the laser via USB. When the program starts for the first time, a window appears indicating a new connection. Enter a name you wish to use and click “OK”. When the next window opens, select the appropriate COM port in the “Connect Using” box and click “OK”. The final window configures the COM port. The port should be configured with 19200 bits per second, 8 data bits, parity of none, stops bit of 1, and Flow Control of None. Click “Ok”. The communication window is now displayed.

The laser power is controlled by adjusting the amplifier current. To find the maximum amplifier current, type the command “s?”. The maximum current should be displayed. To run the laser at full power, turn up the current to maximum by typing “q= X “, where the X is the maximum current. The laser should now be running at maximum power. After the laser goes through the pre-aligned compression, the output power should be 5 W.

Second Harmonic Allignment

In order to maximize the power of the 532 nm beam, the pump beam must be carefully aligned into the LBO crystal. First, plug in the LBO oven and set the temperature to 148^{o}C. For alignment, rotate the half waveplate to reduce the transmitted power of the beam splitter to 100 mW. Note that there will now be nearly 5 W reflected from the beamsplitter. A beamstop should be placed in the path of the reflected beam. Be careful.

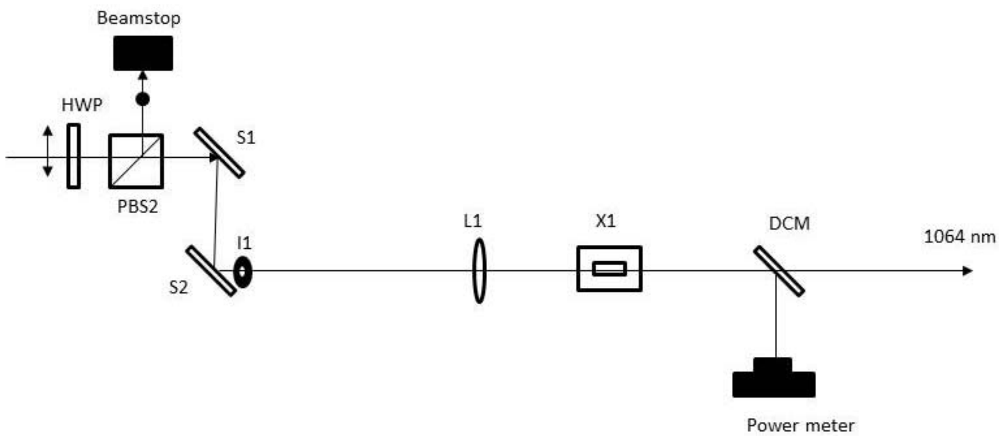

Figure 7. SHG alignment. Using the half wave plate (HWP) and beam splitter (PBS2) are used to attenuate the beam. Steering mirrors S1 and S2 are used to align the beam on the iris (I1) and lens (L1). The power is maximized on a power meter placed after the dichroic mirror (DCM) by adjusting the vertical and horizontal angles of the crystal (X1).

Next, close down the iris I1 until it is roughly the same diameter as the beam. An IR viewer should be used in order to see the beam. Using steering mirror S1, center the beam onto the iris. Now use steering mirror S2 to center the beam on lens L1. Repeat this process iteratively until the beam passes through the center of the iris and the center of the lens. The beam should now be focused into the crystal.

You should now see a faint green beam coming out of the crystal. Place a power meter in the green beam after it has reflected from the dichroic mirror. Rotate the HWP to increase the pump power to maximum. Using the adjustment screws on the mount that holds the oven, make slight adjustments to the vertical and horizontal angles to increase the green power. When optimized, 2 W of green should be measured after the DCM.

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Green Pump Alignment

The first step in aligning the cavity is getting the green beam to focus in the OPO gain crystal (X2). For this alignment, attenuate the green beam using the HWP until it is around 5 mW.

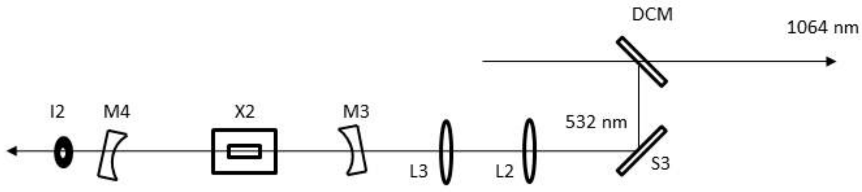

Figure 8. Green alignment. The green beam is centered on the first lens (L2) by adjustment of the dichroic mirror (DCM) and on the iris (I2) with steering mirror S3.

Using the dichroic mirror, center the green beam on the first lens of the telescope, L2. Next, use steering mirror S3 to be centered on iris I2. Repeat this process iteratively until the beam is simultaneously centered on L2 and I2. The beam should now be focused through the crystal.

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Cavity Alignment

Proper cavity alignment requires three things: a) cavity mirrors that are aligned to resonate the cavity mode, b) good overlap between the green pump beam and the cavity mode, and c) matching the cavity length of the OPO to the repetition rate of the pump laser. Alignment is facilitated by the use of an auxiliary beam that can be seen and is still reflected by the cavity mirrors. A visible red diode laser around 700 nm works well for this, and can be included as an option.

The cavity mirrors are highly transmitting for 532 nm, but a small portion is still reflected from each surface. The portion of this beam reflected from curved mirror M4 is used to overlap the beam paths of the auxiliary beam with the pump beam. Referring to the figure below:

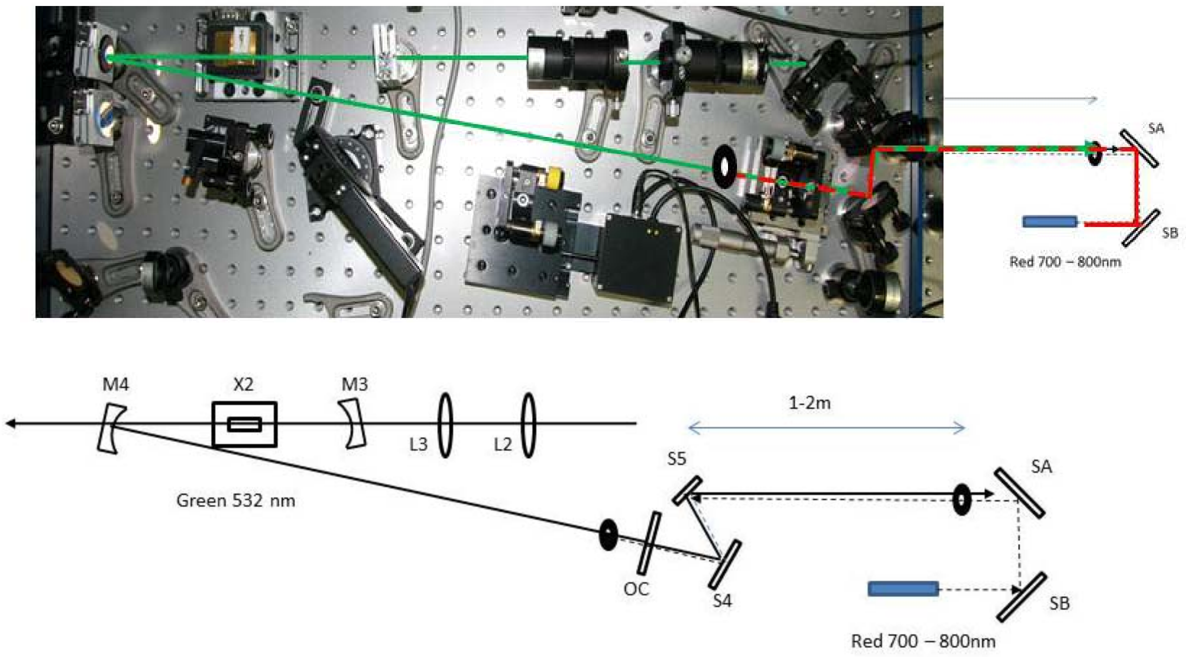

Figure 9. Tracer beam alignment. The red tracer beam is set up outside of the system, and is aligned to be collinear with the green beam using a pair of irises and steering mirrors SA and SB.

1) Insert an iris at a height of 2" just before and centered on the OC.
2) Using M4, adjust the green beam so that it is centered on the iris.
3) Place another iris 1-2 meters away from the first iris, and center the iris on the green beam. These irises now define the path of the green beam.
4) Block the green beam and set up the auxiliary red laser as shown with two steering mirrors SA and SB.
5) Using only SA and SB, simultaneously center the red beam on both of the irises. The red beam is now collinear with the green pump beam.

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Next, the red beam is used to assist in aligned the cavity mirrors.

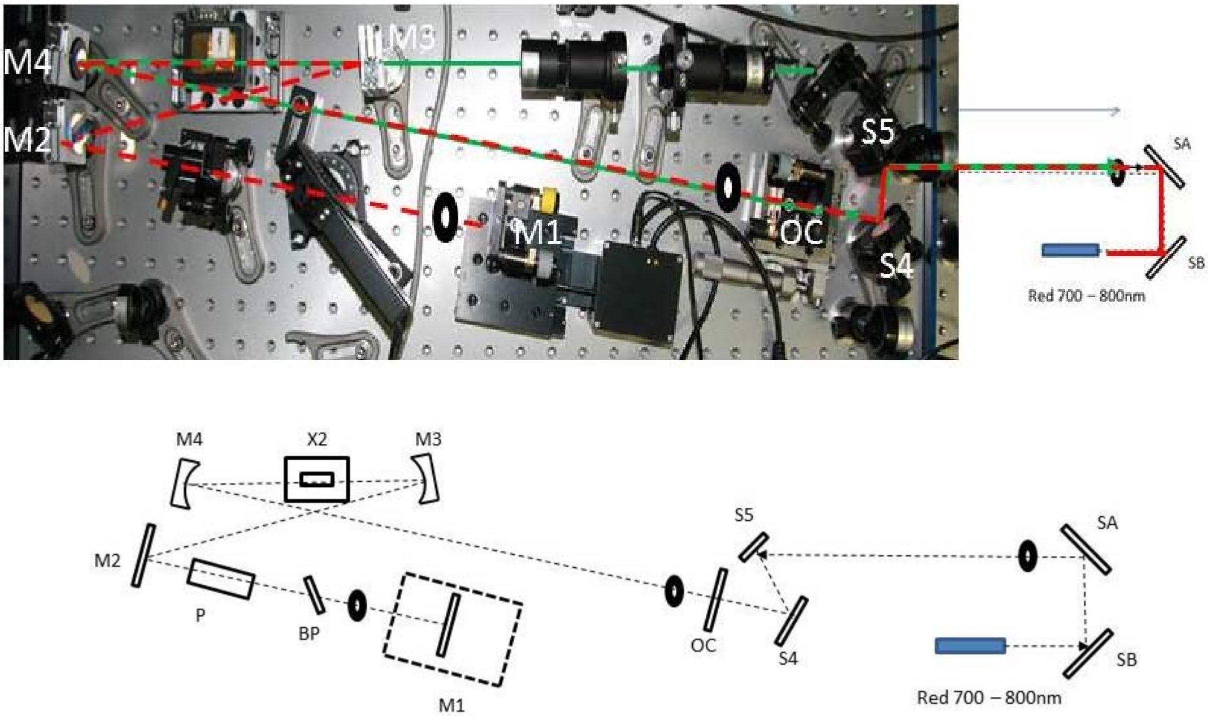

Figure 10. Cavity alignment. The red tracer is aligned through the cavity using a pair of irises positioned by each end mirror in the cavity.

1) Place an iris at a height of 2" just before and centered on M1.
2) Using M3, center the red beam on M2 at a height of 2".
3) Using M2, adjust the beam so it is centered on the iris before M1. The beam should go through the polarizer and birefringent plate without clipping.
4) Don't touch M2, M3 and M4.
5) Using only M1, adjust the beam so it reflects back on itself an goes through both irises.
6) Using only the OC, adjust the beam so that the reflection from the OC is again reflected back on itself through both irises. The cavity is now aligned.

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Oscillation

To achieve oscillation, the length of the cavity must be matched to the repetition rate of the pump laser. The length of the cavity is adjusted by translation of M1 with the computer controlled translation stage.

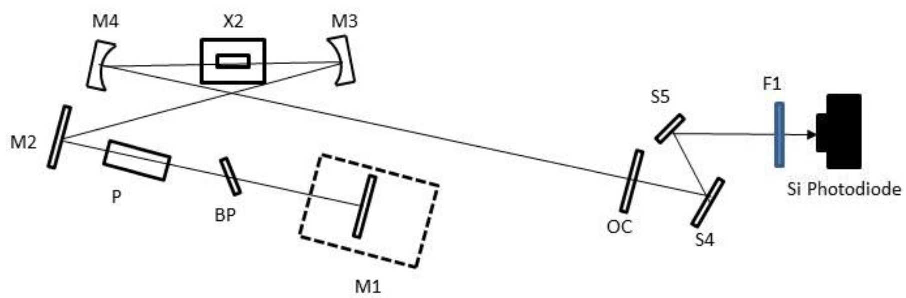


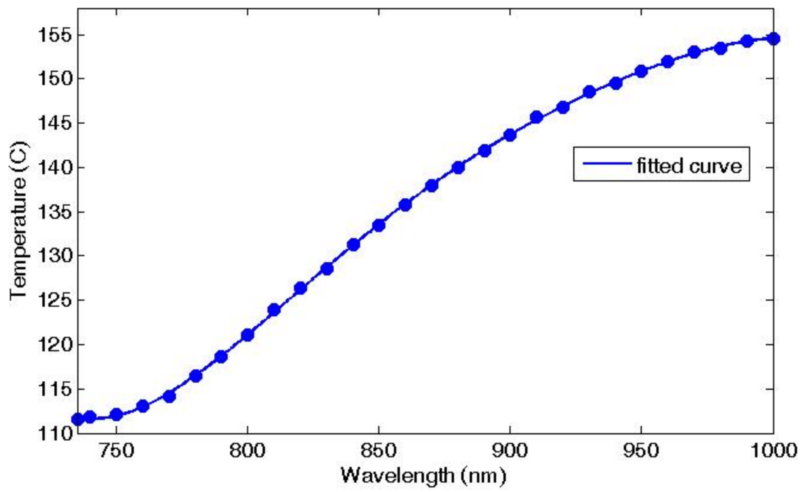
Figure 11. Initial oscillation. A silicon photodiode is placed after the output coupler and filter. Moving the end mirror M1 with the stage will adjust the cavity length to match the pump laser, at which point oscillation will occur.

1) Turn on the oven for the cavity gain crystal. Set the temperature to 120^{o}C.
2) Unblock the green beam.
3) Place a silicon photodiode at the output of the OPO. Remove the filter and center the photodiode on the green beam. Replace the filter.
4) Turn the power to maximum.
5) Using an oscilloscope, look at the output of the photodiode while making small (~1mm) steps with the stage. When the OPO comes onto resonance, a brief flash will be seen. Continue making smaller and smaller adjustments to the cavity length until the signal is maximized.
6) Remove the photodiode and replace with a power meter.
7) Make small adjustments to the cavity alignment using M1 and the OC to maximize the output power.

The output of the OPO is a Class 4 laser, and all necessary safety precautions must be taken when operating. Consult your laser safety officer for proper laser safety.

Tuning

The signal wavelength of the OPO can be tuned from 740 to 1000nm. Tuning is done with a combination of: crystal temperature, cavity length, and rotation of the birefringent filter. Calibrated tuning curves have been provided for the temperature and rotation angle as a function of wavelength. Shown below are measured curves and fits for both temperature and wavelength. The temperature curve gives the set temperature for a given signal wavelength



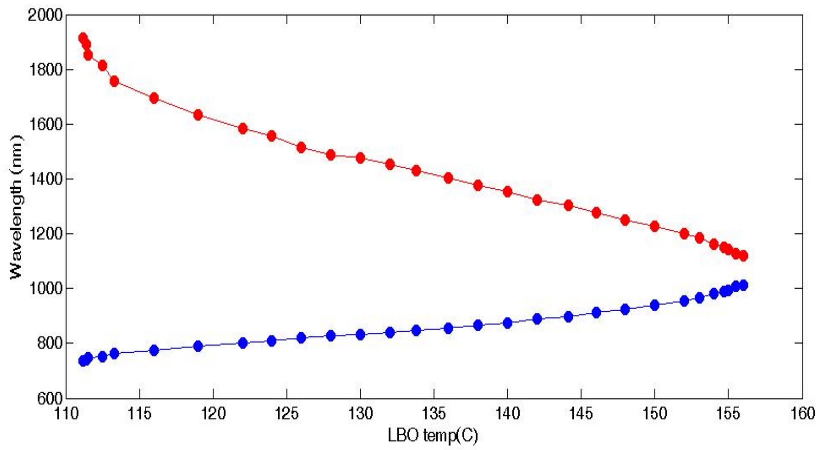


Figure 12. Temperature tuning curve for signal beam, showing the LBO set temperature as a function of the desired signal wavelength (top). Signal (blue) and idler (red) as a function of LBO temperature, showing the relations between signal and idler wavelengths (bottom).

For the rotation angle, a given angle can support several different wavelengths. As shown in the plot below, there are four different curves corresponding to different wavelength regions. The bandwidth of the filter and temperature of the crystal ensure that only one wavelength will oscillate for a given angle.

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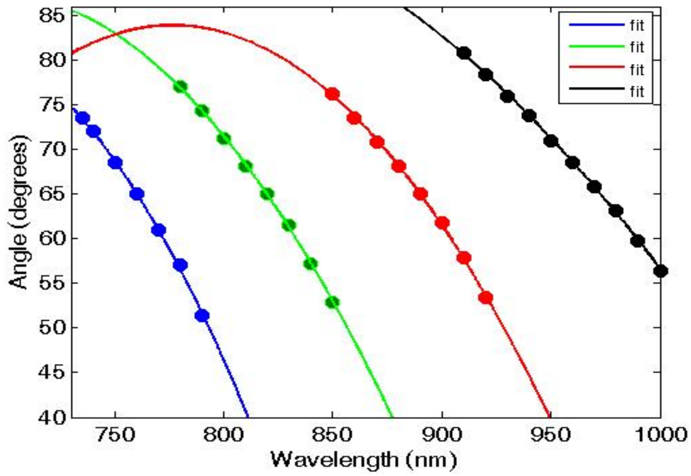

Figure 13. Tuning curve for rotation of birefringent filter plate.

Once the angle and temperature are set, the stage is moved to bring the cavity into resonance. Small adjustments of the cavity length can then be used to optimize the power.

Software

The LabView software provided makes tuning largely automated. Below is a screen shot of the front panel, highlighting the main parts of the program.

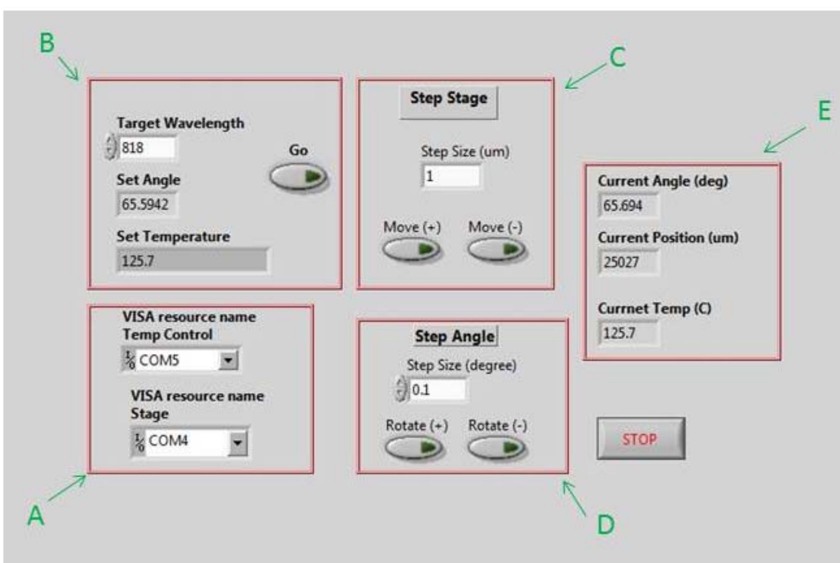

Figure 14. Front panel of control software.

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Panel A

The user entered COM ports for the temperature controller and the linear stage.

Panel B

Target Wavelength**:** User entered desired signal wavelength

Set Angle**:** Angle calculated from the calibration fits at the target wavelength

Set Temperature**:** Temperature calculated from the calibration fit at the target wavelength

Go: After wavelength is entered, press to rotate stage and tune oven to set angel and temperature

Panel C

This sets the stage step, and jogs the linear stage either forward or back by that amount.

Step Size**:** User entered step size of the linear stage in µm

Move (+) and Move (-): When pressed, will jog the stage in the appropriate direction by the amount entered in Step Size. A negative move will increase the cavity length, a positive move will decrease the cavity length (due to orientation of the linear stage).

Panel D

This is used for small adjustments of the rotation angle of the birefringent filter.

Step Size**:** User entered rotation increment of the rotation stage in degrees

Rotate (+) and Rotate (-)**:** When pressed, will jog the rotation stage in the appropriate direction by the amount entered in Step Size

Panel E

Current Angle**:** The current measured setting of the rotation stage in degrees

Current Position**:** The current measured setting of the linear stage in µm. Because of the way the stage is oriented, the minimum value of 0 corresponds to maximum cavity length, while the maximum value of 28000 corresponds to the minimum cavity length.

Current Temp**:** The current measured temperature of the oven in ^{0}C

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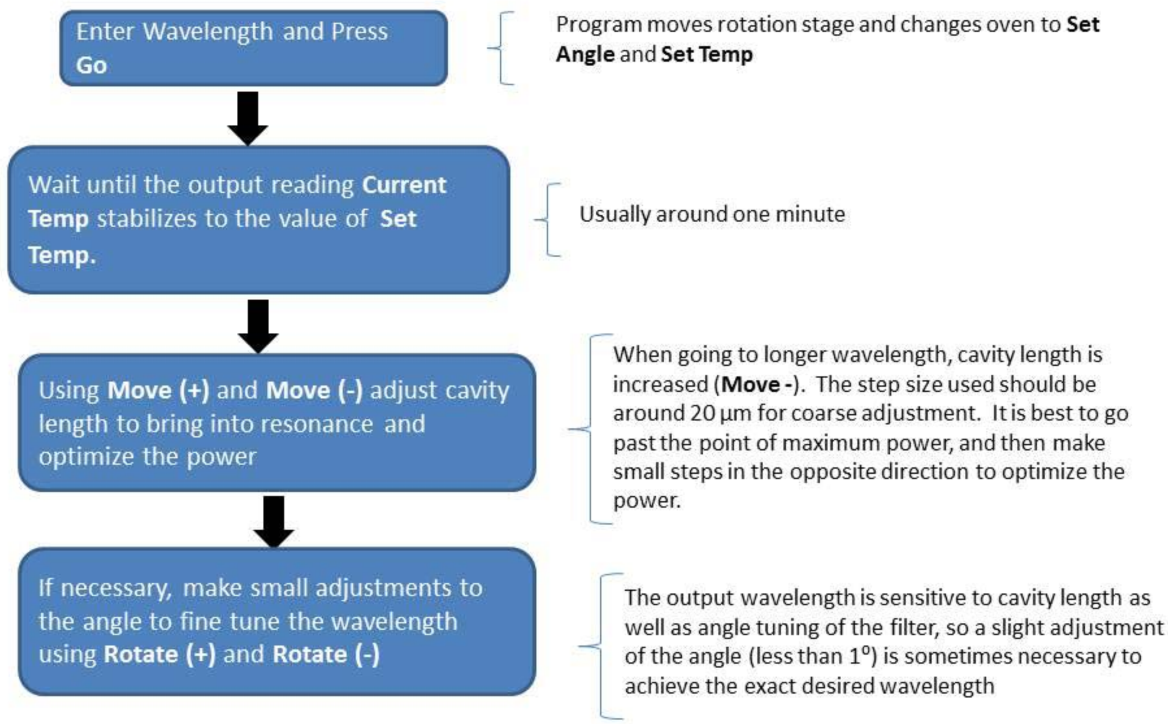
Tuning Procedure

Before starting the tuning procedure, it is necessary to monitor the output power and wavelength. The power is monitored by placing a power meter at the output of the OPO. The wavelength is monitored by a spectrometer that monitors the portion of the beam leaking through M1. If the system is purchased with the spectrometer option, a spectrometer is included that is pre-aligned. Once the power and spectrum are monitored, the following procedure using the provided software is performed to tune to any desired wavelength from 735-1000 nm.



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