Mode-Locking in an Erbium-Doped Fiber Laser

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Overview

• Purpose

• Theory
  – Lasers
  – Mode locking

• Piecewise testing of fiber laser parts
  – Amplifier
  – Enclosed laser
  – Mode locked laser

• Conclusion
Purpose- Why Erbium?

• ~femtosecond pulses from large bandwidth
• Erbium is cheaper due to the telecommunication industry
• Erbium doping offsets dispersive effects from standard fiber
Theory

• Parts to a laser
  – Pump
  – Lasing material
  – Optical cavity
• Lasing occurs in the erbium-doped fiber as electrons are excited by pump light
Mode Locking Intro

- The most common way to get picosecond or smaller pulse durations is through mode locking.
- Mode locking works by locking all of the different modes within a laser cavity to a fixed phase.
- In our case, achieved with wave plates.
Mode Locking Continued

• The sum of the time-domain powers of each mode reduces to: \( P(t) = P_{0} \sin \frac{t}{2} \left[ \frac{(2n+1)\pi \cdot f_{rep} \cdot t}{\sin \frac{t}{2} \left( \pi \cdot f_{rep} \cdot t \right)} \right] \)

• The top figure shows the normalized time-domain power for different \( n \).
  - Notice the decrease in peak width for increased \( n \).

• The bottom figure shows the power dependence on \( n \) at \( t=0 \) (the max power)
  - This shows the large increases in peak power as more wavelengths are added.

• **MORE BANDWIDTH = MORE WAVELENGTHS = MORE POWER + SHORTER PULSES**
EDFA (Erbium-Doped Amplifier) Test

- Use pump to excite erbium fiber and a 1550 nm Menlo laser to stimulate photon emission
- Able to measure pump power vs. input current
- Close to 15 dB theoretical value
Enclosed Laser Schematic

- **Laser Cavity**
- **Lasing Medium**
- **Pump**

Components:
- **Output Coupler**
- **Light Flow**
- **Optical Power Meter**
- **Isolator**
- **.5m Erbium Doped Fiber**
- **WDM**
- **Splice**

Connections:
- Laser Pump and Mount
- FC/APC connections
Enclosed Laser Test

• Output coupler installed and a loop created to make a laser cavity.
• Creates a loop from the amplifier for amplification of power with every pass.
• Limited in maximum power by gain saturation
Mode-Locked Schematic

10% Power Output
Alignment Input
".5m Erbium Doped Fiber"
"Laser Pump and Mount"
"WDM"
"FC/APC"
"Splice"
"Output Coupler"
"Collimator ⊂ λ/4 λ/2 ⊂ Beam-splitter ⊂ λ/4 ⊂ Collimator"
"Free Space"
"Light Flow"
The Final Product
Mode Locking Tests

- Polarizers installed and rotated to achieve mode locking
- Broad optical spectrum consisting of many wavelengths
- Oscilloscope output shows pulse travelling in cavity; depends on cavity length
- Data taken at 254 mA of pump laser current
- ~400 femtosecond pulse width measured
Conclusion

• Currently have a working mode locked erbium fiber laser with a 2.66 mW power output and pulse width of ~400 femtoseconds.

• Future plans to optimize the system further to yield shorter pulse widths by attempting to get a broader optical spectrum.
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Autocorrelation and Pulse Width

- Achieving a small ~fs pulse width for this fiber laser is one of the main goals.
- Autocorrelator used to convert the small pulses into something measurable.
- Works much like a Michaelson interferometer.
- Measured pulse width of ~400 femtoseconds.

![Auto-Correlator Output](image_url)
Autocorrelator Calculation

- Conversion from mirror distance into time traveled:
  \[ \frac{1}{v} = \frac{1}{c} = \frac{1}{3 \times 10^{14}} = 3.33 \times 10^{14} \]
  \[ -15 \text{ s/\(\mu\)m} = 3.33 \text{ fs/\(\mu\)m} \]

- Full-width half-maximum from autocorrelator is -19.839 \(\mu\)s
- Slope from calibration is -27.369
- Pulse Length = (FWHM)(Slope)(0.7) = (-19.839)(-27.369)(0.7) = 380.1 fs

![Auto-Correlator Calibration Graph](graph.png)

**Graph Equation:**
\[ y = -27.369x - 3028.5 \]
**R^2:** 0.99992
Radiofrequency (RF) Spectrum

- Shows the frequency at which laser light circulates within the cavity
- Peak location depends on the cavity length
- This plot was obtained as a final optimization of the laser parameters.
- A good RF spectrum will resemble a single, sharp peak and have no fringes