Elimination of Self-Pulsations in Dual-Clad, Ytterbium-Doped Fiber Lasers

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Summary

Complete suppression of self-pulsations in fiber lasers is demonstrated

- Self pulsations are induced by the interaction between the photon population and the population inversion.
- A long section of passive fiber in the laser cavity makes the round-trip time long compared to the rate at which the pump replenishes the gain.
- Self-pulsations in a watt-level, dual-clad, ytterbium-doped fiber laser have been completely eliminated.

This technique provides a robust and simple solution for eliminating self-pulsations in high-power fiber lasers.
High-power fiber lasers suffer from self-pulsations

- All types of lasers show signs of relaxation oscillations
  - interaction between the photon and inversion populations
  - typically observable in the noise (i.e., RF) spectrum

- These oscillations often become unstable in fiber lasers
  - the dynamic behavior depends on the pump level

- High-power fiber lasers (including commercial ones) suffer from self-pulsations in some regimes of operation.

- Self-pulsations in high-power fiber lasers can damage the laser system.
The self-pulsations are experimentally measured in a conventional linear cavity.
Self-pulsing is caused by the interaction of pumping and the photon emission.

The population inversion and output-signal envelope in the self-pulsing regimes.

<table>
<thead>
<tr>
<th>Pump Rate</th>
<th>Dynamic Behavior</th>
<th>Population Recovery Time</th>
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<tbody>
<tr>
<td>Low</td>
<td>Sustained self-pulsing (SSP)</td>
<td>Many-cavity round trips</td>
</tr>
<tr>
<td>Moderate</td>
<td>Self mode locking (SML)</td>
<td>Single-cavity round trip</td>
</tr>
<tr>
<td>High</td>
<td>cw</td>
<td>Much less than a single cavity round trip</td>
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</tbody>
</table>
The regime of sustained self-pulsations (SSP’s) has been measured for our fiber laser.

- For a low pump rate, the laser enters the SSP regime due to undamped relaxation oscillations
  - pulse-train period $\sim 20 \mu s$
  - the period is related to the relaxation oscillation of the fiber laser
Self-mode-locking (SML) has been observed in the fiber laser at a higher pump rate.

- For a higher pump rate, the gain is replenished rapidly such that a single round-trip through the cavity provides sufficient gain for oscillation.
  - pulse-train period \( \sim 300 \text{ ns} \)
  - the period corresponds to the cavity round-trip time
No previous methods eliminate self-pulsations at all pumping levels

- **Electronic feedback to the pump-laser** power shifts the gain and phase.\(^1\)
- **Resonant pumping near the lasing wavelength** prevents rapid depletion of the gain.\(^2\)
- The fast saturable gain of a **semiconductor optical amplifier in the fiber-laser cavity** prevents instability growth.\(^3\)
- The narrow passband of a \(\lambda/4\)-shifted FBG structure in a ring cavity limits the number of longitudinal cavity modes preferring cw operation.\(^4\)
- **Double-ended pumping** provides more-uniform pumping to reduce pulsation initiation via saturable absorption.\(^5\)
- **A ring cavity with an isolator** prevents SBS as an initiation mechanism.\(^6\)

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Self-pulsations are suppressed by inserting a long section of passive fiber into the laser cavity.
The self-pulsation regimes have been completely eliminated by increasing the laser cavity length.

- The modulation depth is a measure of the competition between self-pulsing and cw modes of operation.
This simple scheme has many advantages over other methods

- An inexpensive single-mode fiber at 1.55 $\mu$m costs only about $80$/km.
- No alignment required—the fiber can be fusion spliced.
- No active components or electronics.
- The slope efficiency degrades only a few percent due to the scattering loss of the passive fiber.
- This scheme can be easily integrated into existing fiber laser systems, such as a linear or ring-cavity laser system as shown below.
Stimulated Raman scattering (SRS) can occur in high-power fiber lasers having such long cavity lengths

• The SRS threshold is about 20 W in a 1-km-cavity fiber laser.
• SRS can be mitigated with appropriate filters
  – in-line short-pass filters
  – wavelength division multiplexers (WDM’s)
  – hole-assisted single-polarization filters\(^1\)

• Large-mode-area (LMA) fibers can be used to suppress SRS by reducing the optical intensity
  – The effective length of fiber that contributes to SRS is much smaller than the physical length of fiber

Our method counters self-pulsations regardless of initiation mechanism

- Initiation mechanisms include
  - saturable absorption of under-pumped gain fiber
  - stimulated Brillouin scattering (SBS)
  - Kerr nonlinearity

- Our laser with a 2349-m cavity works at 1.4 W, above nonlinear thresholds
  - SBS threshold is about 0.7 W
  - Kerr threshold is about 0.2 W

Strict cw operation is observed even when the laser operates well above nonlinear thresholds.
Summary/Conclusions

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