Single-Frequency Hybrid
Brillouin/Ytterbium Fiber Laser

W. Guan and J. R. Marciante
University of Rochester
Laboratory for Laser Energetics
Institute of Optics

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Summary

A single-frequency hybrid Brillouin/ytterbium fiber laser has been demonstrated

- SBS gain acts as a narrowband filter in a ring cavity to enable single-frequency operation

- The Brillouin pump is coupled into the ring cavity through the amplifier before entering the Brillouin gain medium
  - a short length of passive fiber is required
  - low Brillouin pump power is required

- The laser works in the single-frequency regime

- The laser architecture is power scalable without changing the Brillouin pump power.
The Brillouin process in fiber lasers leads to ultra-narrow bandwidth laser sources

- Brillouin fiber lasers require a narrow-bandwidth laser source to pump the Brillouin process.
- The Brillouin process leads to a laser with low-noise-output characteristics.
  - Brillouin laser outputs have much narrower bandwidths than the Brillouin pump
    - a linewidth reduction of 100 has been demonstrated*
  - the intensity noise of the Stokes wave in Brillouin fiber lasers is much less than the pump laser
    - intensity noise reduction of 20 dB has been demonstrated*
- Such narrow-bandwidth lasers are required in
  - coherent communications
  - high-resolution spectroscopy

A Brillouin fiber laser can generate single-frequency output but has difficulty in scaling to high power.

- Brillouin scattering in fiber generates a narrowband (~20-MHz) filter.
- The Brillouin pump must be resonant with the cavity for high intracavity intensities
  - short passive fiber = single-frequency operation*
- The output power scales with the narrowband Brillouin pump power that is limited to a relatively low level

Hybrid Brillouin/erbium fiber lasers can generate high-output power, but cannot generate single frequency.

- The isolator and amplifier eliminate the resonance requirement between the Brillouin pump and the cavity.
- Reduced Brillouin pump intensity requires longer passive fiber as the Brillouin gain medium
  - the laser runs in the multiple-frequency regime
- Output power scaling requires higher Brillouin pump power

Our hybrid Brillouin/ytterbium fiber laser generates high-power, single-frequency output

- The Brillouin pump is injected into the cavity via the amplifier before the Brillouin gain medium
  - short passive fiber = single-frequency operation
- Amplification before Brillouin conversion has two benefits
  - low Brillouin pump powers are required
  - high-output power does not require higher Brillouin pump power since it is achieved with a high-power amplifier
The laser output power reaches 40 mW with a 9-mW Brillouin pump

- Highly ytterbium-doped fiber minimizes cavity length for single-frequency operation
- 1030/1053 WDM provides filtration for maximum laser gain at 1053 nm
- The output power can be scaled with a higher 976-nm pump rather than with a high-power Brillouin pump
The optical signal-to-noise ratio (OSNR) is greater than 50 dB

- 976-nm pump power = 370 mW
- Brillouin pump = 9 mW
The laser operation can be described as injection locking to the Brillouin Stokes wave.

- The laser is free-running (i.e., unlocked) with less than 4 mW of Brillouin pump power.
- Partial locking is observed between 4 and 9 mW.
- Full locking to the Brillouin Stokes wave is achieved with 9 mW of Brillouin pump power.

\[ P_{976} = 370 \text{ mW} \]
The single-frequency behavior has been verified with a scanning Fabry–Perot spectrometer.

• The mode spacing of the laser cavity is approximately 16 MHz.
• The free spectral range (FSR) is 1 GHz and the finesse is about 160, giving a resolution of 6.3 MHz.
• All longitudinal modes can be resolved by the Fabry–Perot spectrometer.

The laser operates with a single frequency.
The relative intensity noise (RIN) is less than $-135 \text{ dB/Hz}$.

- The RIN is measured with an electrical spectrum analyzer (ESA).
- The RIN is shot-noise limited beyond 80 MHz to around $-150 \text{ dB/Hz}$.
- The low peaks are generated by the side-mode noise and relaxation oscillations.
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  - a short length of passive fiber is required
  - low Brillouin pump power is required
- The laser works in the single-frequency regime
- The laser architecture is power scalable without changing the Brillouin pump power.