Integrated 30GHz passive ring mode-locked laser with gain flattening filter

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Abstract: We demonstrated a 30GHz integrated InGaAsP/InP ring mode-locked laser with a gain flattening filter that doubles the locking bandwidth and decreases the pulse width from 840fs to 620fs.

1. Introduction

InGaAsP/InP mode-locked lasers (MLLs) operating at 1.55µm wavelength are compact and stable pulsed sources with typically 10-100GHz repetition rates, which makes them attractive components for optical time division multiplexing (OTDM) [1], multi-wavelength sources [2], low-noise microwave oscillators [3], clock distribution systems [4], and optical samplers for electro-optic analog-to-digital conversion [5-6]. Ring MLLs based on low-cost photolithography can be integrated with a wide variety of functional elements on the InGaAsP/InP platform to build photonic integrated circuits (PICs).

Shorter pulses require wider locking bandwidth, and allow faster data rates for fiber communication, higher peak powers for clock distribution, and higher sampling rates for electro-optic analog-to-digital converters. For these reasons, there have been a multitude of studies focused on cavity design and material selection to shorten the pulse width; however we are not aware of any previous work on integrated mode-locked lasers with gain flattening filters. Gain flattening filters based on thin film dielectrics or fiber gratings are commonly used for EDFAs to correct nonuniform gain across the C-band. For this reason, there have been several studies on the use of gain flattened EDFAs in fiber mode-locked laser [7].

For mode-locked lasers with a saturable absorber region, multiple wavelengths lase simultaneously with fixed phase creating high peak-power pulses necessary to saturate the absorber. For a given material, the locked bandwidth of the mode-locked laser is limited by dispersion and gain competition due to the parabolic gain profile. By applying a filter, the net cavity gain can be flattened allowing more modes to lase. These filters can be made by standard processing on a variety of material platforms for bulk, quantum well, and quantum dot semiconductors. As dispersion is typically low for semiconductor materials and can be compensated for with an AWG [8-9], integrated gain flattening is a vital tool for dramatically increased mode-locking bandwidth.

2. Passive mode-locking at 30GHz

100µm long restricted multimode interference (MMI) couplers in a Mach-Zender interferometer (MZI) configuration were used to create an intra-cavity tunable filter as shown in figure 1. The couplers have nearly 50/50 coupling across the C-band with <1dB insertion loss, and tapered entry and exit paths to minimize reflections. A standard offset quantum well (OQW) InGaAsP/InP integrated platform is used with 7 QWs positioned above a 300nm tall 1.3Q waveguide with a confinement factor of 7.1%. A wet-etch removes the QWs for low loss passive waveguides followed by a single blanket p-cladding regrowth [10]. The total cavity length is 2600µm, the waveguide width is 1.8µm, and the total etch depth is 5µm. The device has output waveguides flared to 5µm and angled at 7° to minimize back-reflection into the cavity. The MZI filter has one 450µm gain arm with a semiconductor optical amplifier (SOA) and one 464µm phase tuning arm based on current injection to provide a ~40nm free spectral range (FSR) with a tunable extinction ratio and pole placement across the C-band. The laser threshold current was 80mA and the typical lasing power at mode-locking was ~6mW measured from the reversed biased MZI gain path.

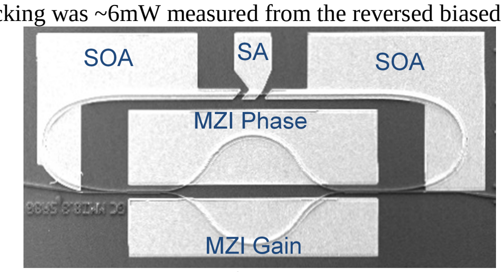

Figure 1: SEM image of mode-locked laser with an integrated MZI filter for gain flattening.

The MZI filter was turned off by applying a -5V bias to the MZI gain path which absorbed >30dB of the light propagating through it. The ring SOA drive currents and the saturable absorber (SA) bias were varied to find the most optimal pulse. The output pulse train goes through a polarization controller and erbium doped fiber amplifier (EDFA) before detection in a second harmonic generation (SHG) based Inrad autocorrelator. With the filter off, the ring SOA drive current is 158mA for -4V SA bias. The pulses are best fit by a Lorentzian distribution with 840fs FWHM shown in figure 2, along with an optical spectrum FWHM of 2nm. The filter is turned on by forward biasing the MZI gain path and adjusting the phase pad to place a zero near the previous lasing wavelength with ~1.5dB extinction ratio. With MZI SOA current of 39mA and ring SOA current of 110mA for -4.4V SA bias, the Lorentzian pulses have 620fs FWHM and an optical spectrum FWHM of 4nm, shown in figure 3. The ideal mode-locked pulses have been calculated from the measured spectral data and show good matching to a Lorentzian shape. These pulses represent the time-bandwidth limit for the locked optical spectrum. The measured pulses are 27% and 40% from this limit with the filter off and on respectively; cavity dispersion effects are likely responsible for limiting the measured pulse width, as indicated by the wider locking bandwidth producing pulses farther from ideal. The RF spectra of the mode-locked laser with the filter on is shown in figure 4 with the RF peak power >50dB above the noise floor and a -20dB linewidth of ~600kHz.

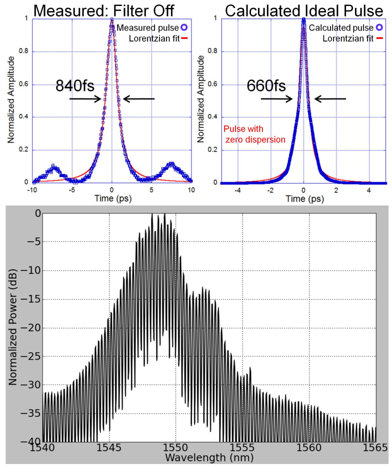

Figure 2: Filter off, measured and calculated autocorellation trace (top), optical spectrum (bottom).

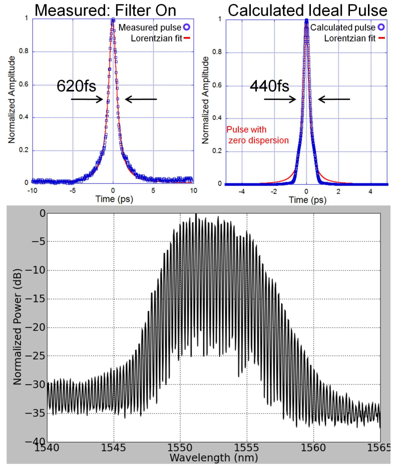

Figure 3: Filter on, measured and calculated autocorellation trace (top), optical spectrum (bottom).

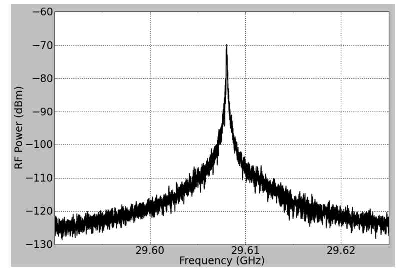

Figure 4: RF Electrical Spectrum with the filter on.

The MZI filter was characterized by injecting 3mW optical power from an external broadband ASE source into the cavity. The cavity SOAs were reversed biased to prevent resonance and nearby SOAs were turned on to provide similar levels of heating to the filter as would be experienced from the ring SOAs at lasing. The results matched well to simulations as shown in figure 5. The simulation accounted for the separate MZI phase and gain arms along with a nonuniform gain profile on the SOAs. The filter increases losses near the lasing peak; this counteracts the gain competition and effectively broadens the lasing spectra allowing more modes to lock together.

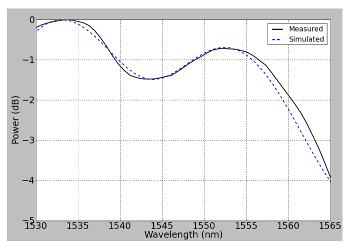

Figure 5: Measured and simulated MZI filter (39mA MZI SOA, 0mA phase pad).

An integrated ring mode-locked lasing with an intra-cavity MZI filter for gain flattening has been fabricated. The filter doubles the mode-locking bandwidth from 2nm to 4nm while decreasing the pulse width from 840fs to 620fs. The 30Ghz repetition rate, wide locking bandwidth, and narrow pulses make this device attractive for OTDM, sensing, and multi-wavelength generation, while the ring design makes it highly suitable for integration with other components in PICs.

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