

16-channel \times 100-GHz Monolithically Integrated O-CDMA Transmitter with SPECTS Encoder and seven 10-GHz Mode-Locked Lasers

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Abstract: We demonstrate a fully-integrated O-CDMA transmitter by monolithically integrating 7 colliding-pulse mode-locked lasers with two arrayed waveguide gratings and 16 phase modulators in InP technology.

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1. Introduction: O-CDMA Photonic Chip

Optical code division multiple access (O-CDMA) technology is a promising candidate for the next generation local access networks such as the realization of fiber-to-the-premise (FTTP) with recent field trials and laboratory studies demonstrating over 320 Gb/s network capacity [1, 2]. Development of photonic chip O-CDMA transceivers will reduce the cost of O-CDMA allowing for its widespread deployment. Spectral phase encoded time-spread (SPECTS) operates by encoding the spectral phase of a sub-picosecond optical pulse to spread the pulse in time for transmission (see Figure 1). The receiver reconstructs the short pulse by applying the conjugate spectral phase code to the encoded pulse. Detection of the decoded pulse is based on a nonlinear detection technique, by distinguishing between the large peak power of a properly decoded pulse and the low peak power of a spread-out improperly decoded pulse (see Figure 1). Additional to nonlinear thresholding, the receiver can also use a MLL to perform time gating. A colliding pulse modelocked laser (CPM) generates picosecond optical pulses for the arrayed-waveguide grating (AWG) based spectral phase encoders to apply a phase code at the transmitter and remove the phase code at the receiver. The receiver uses electro-absorption (EA) based Mach-Zehnder interferometer (MZI) to perform non-linear thresholding. Therefore, the transmitter CPM needs to provide a broad spectrum for spectral phase encoding and the receiver CPM needs to provide a short transform limited pulse for time gating. Separate demonstrations of arrayed waveguide (AWG) encoders and decoders, colliding pulse mode-locked lasers (CPM) and Mach-Zehnder interferometers based nonlinear thresholder under identical fabrication procedure proves the InP platform used in this work viable for monolithic integration [3] [4]. Successful integration requires combining the CPM laser cavity on the same substrate as the passive components. Separately in [5] we demonstrated hybrid modelocking of a 10 GHz CPM laser formed by deeply etched mirrors and in [3] we demonstrated a 16-channel InP SPECTS O-CDMA encoder. The focus of this summary is integration of the novel CPM laser formed using 6 μm deeply-etched mirrors (DEM), which was demonstrated as an isolated component in [5], with the SPECTS-OCDMA spectral-phase encoding operation and nonlinear-thresholding time-gating operation.

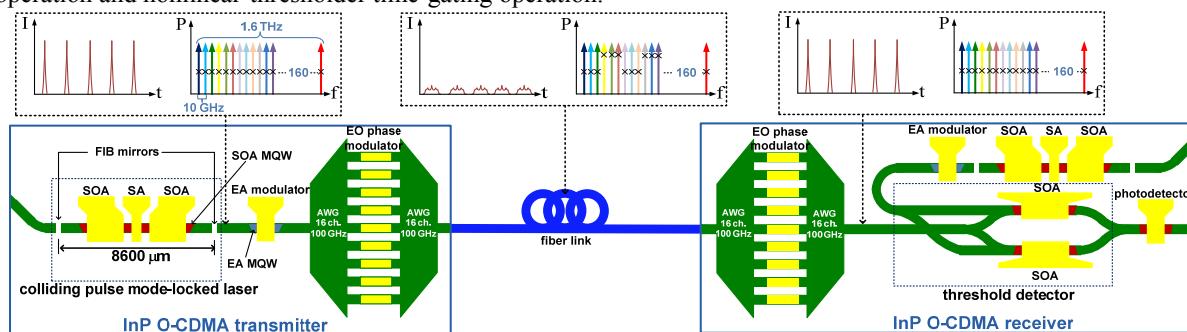


Figure 1 Illustration of the concept of SPECTS O-CDMA showing the schematic layout of the InP O-CDMA transmitter and receiver.

2. InP O-CDMA Transmitter Design and Fabrication

Figure 1 shows a schematic layout of the InP- O-CDMA transmitter. The transmitter consists of a CPM source integrated with a 16-channel \times 100-GHz AWG-pair to encode the phase of the different spectral components of the CPM pulse train. The CPM has two 1000- μm -long gain sections and 45- μm -long EA sections. The mode-locked-laser cavity is formed by focused-ion-beam (FIB) etching of the DEMs (see Figure 2 (a)). Total length of the CPM is 8600 μm , which allows the CPM to resonate at 10GHz. We have introduced an angled facet of 7 degree on the left side of the CPM to suppress any reflections, which might de-stabilize the operation of the CPM. The interfaces between the passive and active regions are angled at 45 degrees to minimize unwanted intracavity reflections which can disrupt modelocking.

The pulse from the CPM is coupled into the AWG-pair encoder. Figure 2 (b) shows the mask layout of the O-CDMA transmitter chip. The AWGs have 16 channels with a channel spacing of 100 GHz. The phase modulators that perform spectral phase coding of the CPM pulse are 4-mm long. We have added delay lines to equalize the path lengths for the different channels. The total device size is 12 mm \times 8 mm.

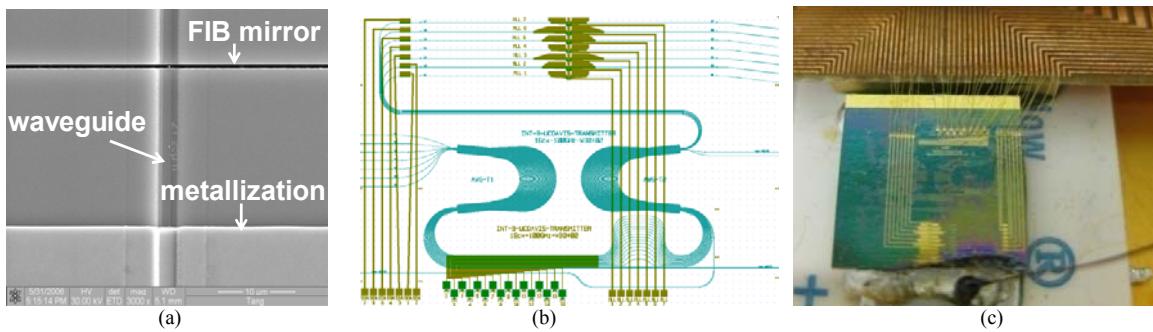


Figure 2 SEM picture of a FIB mirror that has been cut through a waveguide (a), and a mask layout- (b) and a photograph of the fabricated InP O-CDMA transmitter (c).

Fabrication starts with metal organic chemical vapor deposition (MOCVD) growth of the n-doped InP wafer and semiconductor optical amplifiers (SOA) layers, consisting of six 9 nm Q(1.55) quantum wells (MQW) and seven 5 nm Q(1.17) barriers designed for a PL 1545 nm. A regrowth deposits the EA MQWs and a second regrowth the p-doped cladding layers. EA, SOA and passive areas are defined by photolithography and wet etching. Dry-etching defines the waveguides. A Fe-InP layer is regrown for simultaneous passivation of the waveguide sidewalls, electrical isolation, and planarization of the surface for subsequent metallization: (Ti\Pt\Au) on a highly doped InGaAs layer. In order to form the cavity with high reflectivity (67%) and broad bandwidth, DEM is fabricated as follows: First, 100 nm of oxide was deposited via a low temperature PECVD process. Then, using the focused ion beam etching (FIB), a 3 μm wide Pt strip was deposited using a metal organic precursor to enhance sidewall verticality. Finally, the facet was made using the Ga beam at 30kV and 1nA was used to make the strip. Detailed analysis of the reflectivity of the DEM can be found in [5].

3. Encoder characterization

Fig.3 (a) shows typical modelocked pulses from the CPM under passive modelocking measured with a digital communication analyzer (DCA) on the injection-locking side. The optical spectrum of the pulse shown in Figure 3(b) covers over 10 nm of bandwidth. The corresponding optical pulse has width of 3.6 ps. The time-bandwidth product is >1 which is much larger than the theoretical limit of 0.32 for a sech pulse. The mode is locked at 10GHz, while the output power is -15dBm. Assuming the 10 nm of spectrum, the SPECTS-OCDMA encoder should be able to compensate for any of the unwanted chirp that broadens the laser pulse.

Fig.3 (c) shows the spectrum of the AWG pair. The FSR is 23 nm. The non-uniformity among the 16 channels is less than 5dB. Fig.3 (d) and (e) show the experimental results of cross-correlation traces for the signals before and after encoding. The blue curves indicate the pulse being distorted by phase errors on between wavelength channels on the AWG pair waveform shaper. When the reverse voltages to the phase shifters are changed, the waveform changes. This change shows working integrated O-CDMA encoder and colliding pulse modelocked laser.

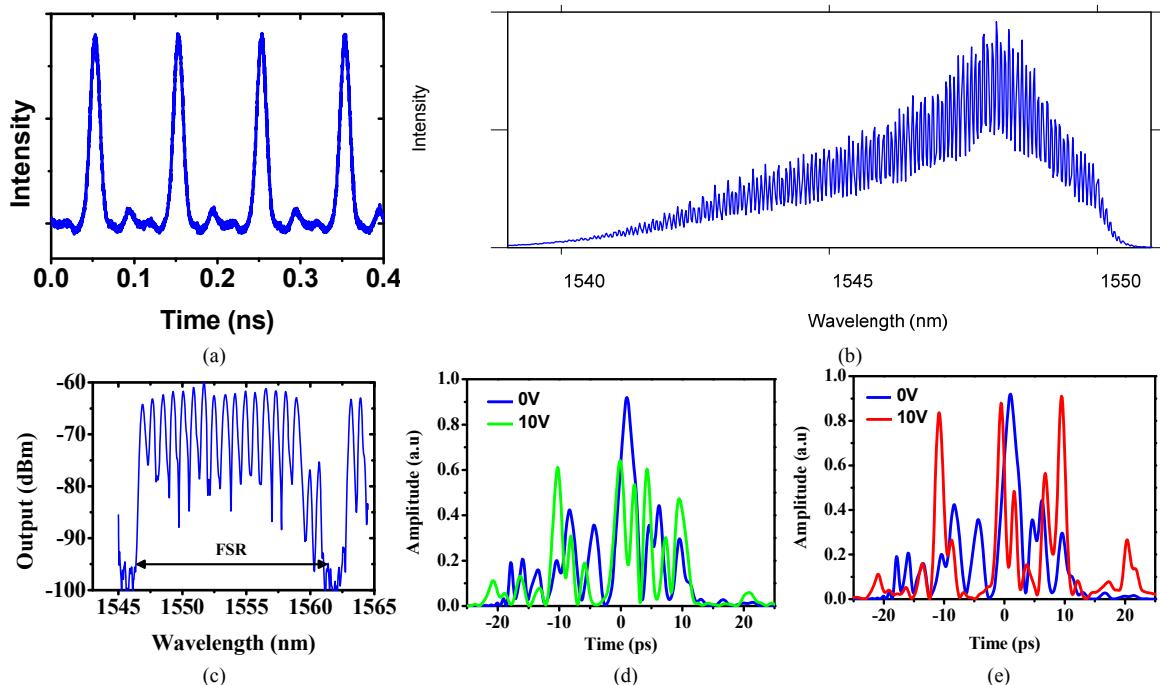


Figure 3 Measured spectrum (a) and DCA trace of the 10-GHz pulse (b). Measured transmission of the AWG-pair O-CDMA encoder (c), and pulse-shaped waveforms while applying 10V to channel # 14 (d), and channel # 15 (e).

4. Conclusion

We have fabricated the O-CDMA transmitter by monolithically integrating FIB-mirror-etched mode-locked laser with an AWG-pair O-CDMA encoder on the same InP wafer. The pulse shaping function has been demonstrated by applying voltages on individual phase modulators. Our next step is to reduce the loss of the chip and to encode all 16 channels at the same time.

5. References

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