Compact InP-Based 16-Channel O-CDMA Encoder/Decoder

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Abstract: A very compact InP-Based 16-channel O-CDMA encoder/-decoder chip (3.8mm x 6.8mm) has been designed, fabricated and characterized. The device successfully performs O-CDMA spectral encoding. Numerous laboratory studies, and field trials[1] of optical code division multiple access (O-CDMA) have proven O-CDMA as a promising candidate for local access networks experimentally demonstrated up to 320 Gb/s network capacity [2]. However, integrated devices for O-CDMA are lacking, especially in the InP platform [3]. This paper presents operation of a 16-channel, spectral-phase encoded time-spread (SPECTS) O-CDMA encoder/decoder[2]. SPECTS O-CDMA operates on the principle of encoding the spectral phase of a sub-picosecond pulse to spread it in time. The encoded pulse is detected by decoding the pulse by applying a conjugate spectral phase code, then by detecting the short pulse using nonlinear detection to distinguish between the large peak power of properly decoded pulse to the low peak power of a spread pulse.

Conventional O-CDMA encoders/decoders employ an AWG-pair: one to de-multiplex the spectral components of the short pulse (the de-mux AWG), and one to multiplex them back together (the mux AWG) after applying the spectral phase code [3]. In this paper, we report an O-CDMA encoder/decoder that utilizes only one AWG that acts as the de-mux- and the mux AWG in a loop-back configuration. This single-AWG-based O-CDMA encoder/decoder offers several advantages over conventional AWG-pair encoders, such as spectral self-aligned mux- and de-mux operation (in contrast to the central-wavelength shift experienced by two different AWGs), size reduction, and simpler phase-error corrections required in only one AWG. Figure 1a shows the layout of the fabricated InP O-CDMA encoder/-decoder chip. The chip contains a 20x20-channel AWG with a channel spacing of 100 GHz, and sixteen 9 mm long electro-optic phase modulators. The input pulse, to be encoded/decoded, is applied to the chip input waveguide, which is connected to the AWG. The AWG then de-multiplexes the spectral components of the pulse onto the 16 AWG outputs that lead up to the 16 phase modulators. The fast electro-optic phase modulators are 9 mm long, and we can control the phase of each individual spectral component by applying a reverse bias to the respective bond pad. After passing through the modulators, the waveguides are coupled back into the input side of the same AWG, who will then multiplex the spectral components of the pulse onto the chip output waveguide. We have added delay lines in order to equalize the optical path lengths for each spectral component of the pulse.

The structure of our 2.4 μm-wide buried waveguide was fabricated using two epitaxial growths. At first, we grew the following layers on an n-doped InP substrate in a metal-organic vapour-phase-epitaxy (MOVPE) reactor: a 2-μm n-doped InP layer, a 0.5-μm Q(1.15) undoped waveguide core layer, a 2-μm p-doped InP top cladding layer, and a 0.2-μm p-doped InGaAs layer. Then, the 2.4-μm waveguides were etched in a Br₂/N₂ reactive beam etcher using a SiO₂ layer as mask. And then, Fe-doped semi-insulating InP was regrown by low-pressure hydrid vapour-phase epitaxy (HVPE). Finally, we patterned the metal lines, and deposited the backside metallization. Figure 1(b) shows a schematic of the finalized waveguide structure.

Figure 1(c) shows the measured transmission spectrum of the O-CDMA encoder/decoder for TE polarization for all 16 channels. These results have been obtained by coupling light from a tunable laser into the chip using a lensed fiber. The output light was captured with a microscope objective, and then guided to the photo detector after passing through a polarizer. The measured transmission spectrum was later normalized to the spectrum measured through a straight waveguide. Proper operation of the SPECTS O-CDMA encoder/decoder was verified by transmitting a 0.8 ps pulse through the encoder with different bias voltages on channel 9 and measuring the encoded pulses transmission using cross-correlation frequency-resolved optical gating (XFROG). XFROG has been verified as a precise and unambiguous intensity and phase characterization tool for complicated waveforms and is therefore ideally suited to measure SPECTS O-CDMA waveforms [4]. The measured XFROG traces are binned to a 256x256 grid and the retrieval errors (G number) are 0.003. Figure 2 (a) shows the SPECTS O-CDMA encoded spectrum (intensity and phase) under 3 different bias voltages applied to channel 9. There is 2.3 rads of phase shift on channel 9 when the reverse bias voltage is changed from 0 to 5V. Although only the phase of one channel is changed, this creates a significant change in the temporal waveforms (Figure 2 (b)). Both temporal waveforms are complex because of the uncompensated phase errors of the delay arms which is shown in the spectrum (Figure 2 (a)).
In conclusion, we have designed, fabricated, and characterized an InP-based O-CDMA encoder/decoder based on a single-AWG loop-back configuration. The chip is 3.8mm by 6.8mm, and showed successful spectral phase coding by changing the phase of one channel by electro optical effects.

References:

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Figure 1 Mask layout of the InP O-CDMA encoder/decoder a), bird's view schematic of the waveguide structure b), and plot of the measured transmission spectrum of the encoder/decoder c).

Figure 2. (a) Spectral intensity (dashed) and phase (solid) of encoded waveform with different reverse bias voltages. (b) Temporal intensity of waveform under different reverse biases. (c) XFROG trace at 0V (d) XFROG trace at 5V showing clear redistribution of pulse energy.