Monolithically Integrated Optical Arbitrary Waveform Generators by Line-by-Line Amplitude and Phase Modulation

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Abstract: We discuss optical arbitrary waveform generation by line-by-line amplitude and phase manipulation of coherent optical comb source using monolithically integrated photonic chips containing arrayed waveguide gratings and amplitude and phase modulators.

Capability to generate optical waveforms of arbitrary phase and amplitude signatures [1] [2] [3] profoundly impacts many application areas including LIDARs, communications, and computing. Among a number of possible OAWG methods, the line-by-line frequency-domain Fourier synthesis [3] [4] of coherent optical combs provides versatile and scalable realization. Recently, waveform shapers (WS) using bulk-optics or arrayed waveguide gratings (AWGs) [4] have successfully created truly arbitrary waveforms using line-by-line Fourier synthesis, which involved independent amplitude and phase modulations of individual spectral lines of an optical frequency comb (OFC). Typically, an apparatus for optical arbitrary waveform generation (OAWG) involves many pieces of bulk optics occupying a table top setup. Monolithic and chip-scale integration of terahertz optical arbitrary waveform generation is necessary for robust and agile operation of OAWG. This paper discusses OAWG on InP and Silica chips.

Fig. 1 illustrates (a) a 64 channel 20 GHz silica planar lightwave circuit based OAWG encoder and decoder realized by an array of thermo-optically tuned amplitude and phase modulators sandwiched by a pair of arrayed-waveguide-gratings, and (b) a 10 channel 10 GHz InP planar lightwave circuit based OAWG encoder and decoder realized by an array of high-speed electro-optically tuned amplitude and phase modulators sandwiched by a pair of arrayed-waveguide-gratings. The OAWG encoders, when amplitude and phase modulation settings are stationary, will generate the encoded arbitrary waveforms of limited length (inverse of the OFC line spacing) repeating at the OFC channel spacing frequency. Both the silica and the InP devices in Fig. 1 can offer reconfiguration of the generated waveforms by changing the modulation conditions on the amplitude and phase modulators. The InP device has the advantage of achieving high-speed reconfiguration (10 GHz and above) comparable to the repetition rate (OFC line spacing of 10 GHz), thus making it possible to achieve truly arbitrary waveform generation if individual modulators achieved high-speed (10 GHz) modulation.

Fig. 2 shows (a) RF-optical packaging of the fabricated InP OAWG device with 10 amplitude modulator drivers and 10 phase modulator drivers at 10 GHz each, (b) a zoom-in photo of the InP OAWG chip in the package, and (c) a mask layout of coplanar transmission lines with RF-optical velocity matched (RF phase velocity matched to optical group velocity) traveling wave phase modulators with segmented ion implantation. The fabricated devices showed traveling wave AM and PM modulation bandwidths exceeding 10 GHz.
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Fig. 3  Generated optical wave forms illustrating intended phase (solid red), measured phase (broken red), intended amplitude (solid blue) and measured amplitude (solid black), for (a) chirped super-Gaussian of sixth order, (b) transform-limited super-Gaussian of sixth order, and (c) five-pulse sequence. The measured waveforms show less than 2 % deviations in normalized energy compared to the targeted waveforms.

Fig. 3 shows generated optical waveforms illustrating intended phase (solid red), measured phase (broken red), intended amplitude (solid blue) and measured amplitude (solid black), for (a) chirped super-Gaussian of sixth order, (b) transform-limited super-Gaussian of sixth order, and (c) five-pulse sequence. The measured waveforms show less than 2 % deviations in normalized energy compared to the targeted waveforms. High-speed modulation of waveforms and single-shot measurements of infinite record-length will also be discussed.

REFERENCES


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