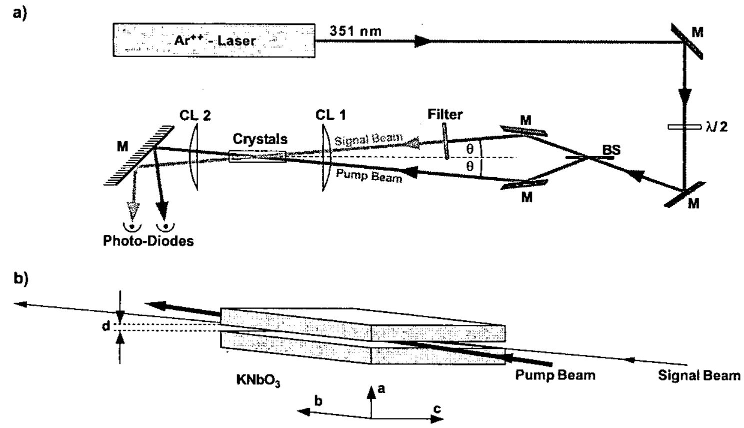
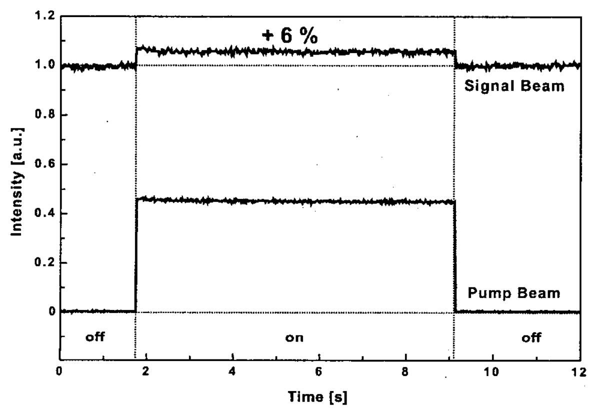


CMH6 Fig. 1. (a) Schematic top view of the experimental setup and (b) side view of the crystal arrangement.



CMH6 Fig. 2. Demonstration of two-beam coupling and energy transfer in a hollow waveguide.

usually observed for interband photorefractive effects in $KNbO_3$.[1]

The most likely physical effect giving rise to the observed coupling is related to the formation of a phase-shifted, non local space-charge grating in the $KNbO_3$ substrates through the interband photorefractive effect. This field modulates the reflectivity at the internal air-$KNbO_3$ interface by means of the electro-optic effect. In addition, a modulated surface corrugation can arise via piezo-electric effects.[3] The role of local absorption and/or thermal gratings is also being investigated.

References

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CMI 10:15 am–12:00 pm

Room: 101B

Optical Modulators: Filters and Applications

Anand Gopinath, Univ. of Minnesota, USA, Presider

CMI1 10:15 am

Using Standing-Wave Electroabsorption Modulators to Generate 40 GHz Optical Pulses

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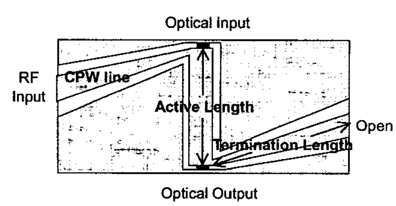
Simple and stable optical pulse sources are needed in modern communication systems because the RZ format is preferred at high bit rates. Electro-absorption modulators (EAM) have been used to generate optical pulses with simple sinusoidal drive[1] and feature low-chirp and low-jitter. To further decrease the pulse width, approaches such as using tandem modulators[2] and dual amplifier drive[3] were reported. In this work, we deliberately constructed electrical standing-wave patterns in the EAM to increase the E-O response and generate shorter pulses.

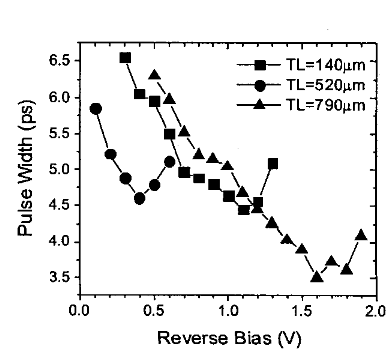
The EAM used in this work is similar to the traveling-wave EAM reported in.[4] The geometry is shown schematically in Fig. 1. The most significant difference is that the end of the CPW line is left open instead of terminated by a 50Ω resistor. The forward propagating microwave is reflected by the open termination and forms a standing-wave pattern along the CPW line. The termination length (TL) is varied by either cleaving or by bonding an extra CPW line. Devices with three different termination lengths are prepared: 140 μm, 520 μm and 790 μm. The active length is 300 μm. The optical input and output are on the two cleaved and AR coated facets. At 1555 nm, the fiber-to-fiber loss is about –20 dB. A modulation efficiency of 20 dB/V in the 0 V to 2 V reverse bias region and a total modulation depth of 47 dB are measured.

These EAMs are driven by a 40 GHz, 5.6 Vpp sinusoidal microwave. A 2 dBm 1555 nm CW laser is sent into the optical input. The output pulses are amplified by EDFAs and then measured by an autocorrelator. The measured pulse width as a function of reverse bias is shown on Fig. 2. It can be seen that EAMs with TL = 790 μm and 140 μm can generate shorter pulses compared to the one with TL = 520 μm. They can also be biased with higher voltage, which leads to higher extinction ratio. The shortest pulse generated with the TL = 790 μm EAM is 3.5 ps. The average output power from the EAM is shown on Fig. 3. The output power is sensitive with respect to the termination length. For example, at the pulse width of about 4.6 ps the output power for the TL = 520 μm, 140 μm and 790 μm EAMs are –32 dBm, –29 dBm and –24 dBm, respectively.

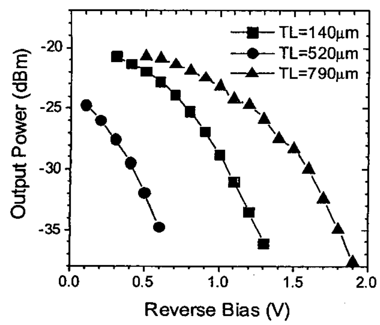
These results can be explained by noting the



CMI1 Fig. 1. Schematic drawing of the EAM.



CMI1 Fig. 2. Pulse width v.s. reverse bias voltage for different termination length.



CMI1 Fig. 3. Output power v.s. reverse bias voltage for different termination length.

fact that the microwave quarter wavelength is about 750 μm and 350 μm in the passive and active sections of the CPW line. Changing the termination length shifts the node of the standing-wave pattern and changes the microwave voltage distribution in the active section. For the TL = 520 μm EAM, the node is approximately in the center of the active section, which degrades the E-O response of the device. The experimental results agree well with detailed theoretical modeling of the device.

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CMI2 — 10:30 am

A Synthesized Electrooptic Directional-Coupler Modulator at 1.3 μm with Low Switching Voltage

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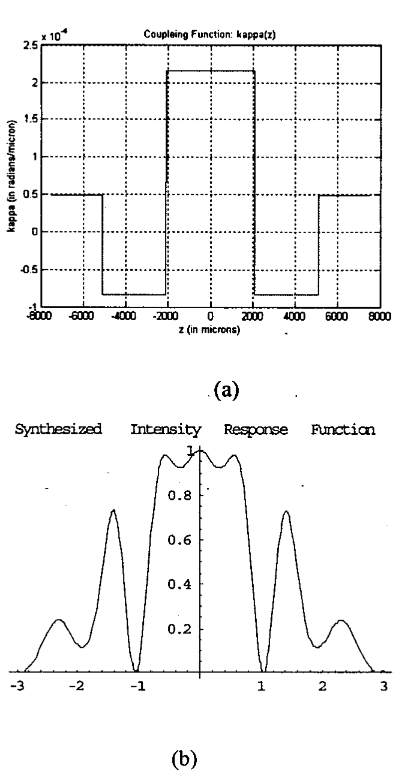
External modulators are used in optical communication systems as directly modulating the light source leads to sprectral broadening, and hence limiting the capacity of the system. Currently, Mach-Zehnder interferometric optical modulators built in lithium niobate substrate are widely used, but these modulators, as well as some other types of optical modulators, have a linear intensity response, and so only a small modulation index of about 2%–5% may be used for analog systems. Several techniques[1–5] are used to improve the linearity of the response function of these optical modulators, so that the dynamic range can be maximally utilized.

In our previous work,[6] the conventional, parallel-waveguide directional coupler, whose response function is intrinsically non-linear, was modified by varying the gap between the waveguides so that the intensity response function became linear. The coupling function of this directional coupler was synthesized using an inverse Fourier transform technique. The device exhibited good linearity, with the third-order-intermodulation-limited spurious-free dynamic range at −130 dB noise floor of 96.2 $dB/Hz^{2/3}$; and the switching voltage was 48 volts.

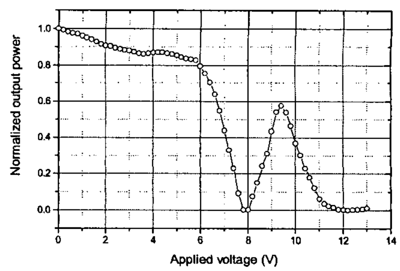
The directional-coupler modulator has been redesigned for a low switching voltage using a discretized, three-step coupling function as shown in Fig. 1(a). The corresponding response function is shown in Fig. 1(b), and the switching voltage is calculated to be 1.2 volts, for a 1.5 cm-long device.

The directional-coupler modulator was designed to operate at 1.3 μm wavelength, and was fabricated in the GaAs/AlGaAs material system. In this design, the gap between the two waveguides is held fixed along the structure, except at the π phase shift regions introduced in one guide relative to the other (the coupling function changes its sign in these regions). There is negligible coupling between the waveguides in these π phase shift regions as the separation between the two waveguides is large. The different couplings are realized by varying the etch depth between the waveguides employing a reactive ion etching (RIE) process.

The devices thus designed were fabricated and tested, and the amplitude response of the device was measured by launching a TE-polarized laser beam into an input arm of the directional coupler. By applying different values of dc voltage to the electrodes on top of the waveguides, the optical output power from the coupled arm of the directional coupler was measured and the result is shown in Fig. 2.



CMI2 Fig. 1. (a) Discretized (step) coupling function; and (b) the corresponding intensity response function.



CMI2 Fig. 2. Intensity response function of our directional-coupler modulator.

The switching voltage of the actual modulator is approximately 1.8 volts which is slightly higher than the design value (1.2 volts) and the shape of the response function of the actual device is also somewhat different from the design, as shown in Fig. 1(b). The discrepancies are probably due to the fabrication tolerances, in particular the etch depth.

In summary, we have demonstrated that the design of the directional-coupler modulator may be synthesized to obtain the desired response functions, so that modulators with high linearity in the response function[6] or with low switching voltage may be realized.

References

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