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Observation of Wavelength-Converting Optical Switching at 2.5 GHz in a Surface-Normal Illuminated Waveguide

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Abstract: We demonstrate proof-of-principle switching of a continuous wave (CW) signal that propagates in a p-i-n multiple quantum well waveguide illuminated from above with a modulated control beam. We observe modulation of the CW signal at 2.5 GHz using ~ 1mW control beam powers.

Desirable features in optically-controlled optical switches include fast operating speeds, high contrast ratios, low switching power, and NxN scalability. Normally, waveguide modulators provide large contrast ratios but provide only 1xN scalability. By having surface-normal control of planar (waveguided) signals, NxN arrays could be achieved. Several groups have simply electrically interconnected surface-normal photodetectors with waveguide switches to achieve such a configuration [1-3]. In this paper we demonstrate an optically controlled waveguide switch that combines the detection and modulation function into a single device [4-5] that, in principle, can provide all of the above features. In addition to optically invoked modulation, we can enable (or disable) the device with an appropriate applied electrical bias. We demonstrate wavelength conversion capability of this device by employing different wavelengths for the control and signal beams (822 nm and 868 nm, respectively).

The device is a multiple quantum well p-i-n diode with a waveguide structure, as seen in Fig. 1. The control beam is coupled into the diode through surface normal illumination while the CW signal is coupled in through the waveguiding direction of the device. Upon detection of the control beam, the absorption properties of the multiple quantum wells in the device are changed, which in turn modulates the CW signal. Consequently, data from the control beam can be encoded onto the CW signal. Thus, switching is achieved by performing detection of the control beam and modulation of the input signal with the same device. Because the detection and modulation occur in the same space, power consumption is decreased and electrical interconnection issues are eliminated.

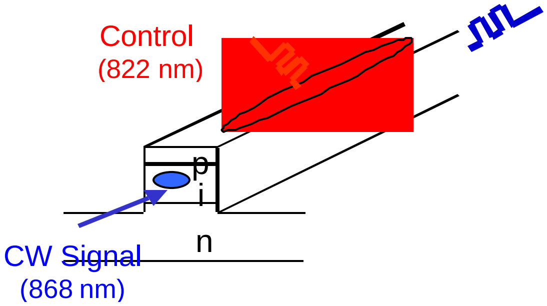

Fig. 1. Schematic of the optically-controlled waveguide switch. The control beam is incident on the top of the device and is absorbed in the intrinsic region. The response of the device to the photogenerated carriers alters the absorption of the quantum wells in the intrinsic region, changing the transmission of the CW input signal beam travelling through the waveguide. Wavelength conversion occurs if the control and signal beams are at different wavelengths.

The waveguide was grown on a *n*+ GaAs substrate using molecular beam epitaxy. The bottom cladding layer consists of 2 µm thick, *n* doped (5×10^{17} cm^{-3} Si) $Al_{0.08}Ga_{0.92}As$. The core contains 8 quantum wells (100 Å GaAs wells and 30 Å $Al_{0.27}Ga_{0.73}As$ barriers) sandwiched between two 4000 Å layers of undoped $Al_{0.05}Ga_{0.95}As$. The upper cladding is composed of 1 µm thick, *p* doped (5×10^{17} cm^{-3} Be) $Al_{0.08}Ga_{0.92}As$ followed by 1 µm thick, *p*+ (2×10^{19} cm^{-3} Be) $Al_{0.08}Ga_{0.92}As$.

We fabricated 25 μm wide, 3 μm deep ridge waveguides designed for single mode operation for wavelengths higher than 860 nm. The *p* contact was deposited on a mesa connected to the waveguide. The wafer was lapped to a thickness of 100 μm with an *n* contact evaporated on the backside. A Si_xN_y layer was deposited on the top of the ridge waveguide to serve as an antireflection coating centered at 827 nm. The waveguides were cleaved to a length of 300 μm; the facets were not anti-reflection coated. The waveguides were epoxied to copper plate mounts for testing.

A tunable Ti-sapphire laser was used as the input CW source. The output was collected using a single mode fiber coupler. The contrast ratio of the waveguide was 18 dB for a 3 V bias range. A gain-switched edge-emitting diode laser operating at 822 nm was used as the control beam to illuminate the length of the waveguide with an elliptical beam approximately 5 μm wide and 300 μm long. The beam was created using a telescope comprised of a cylindrical lens and microscope objective lens.

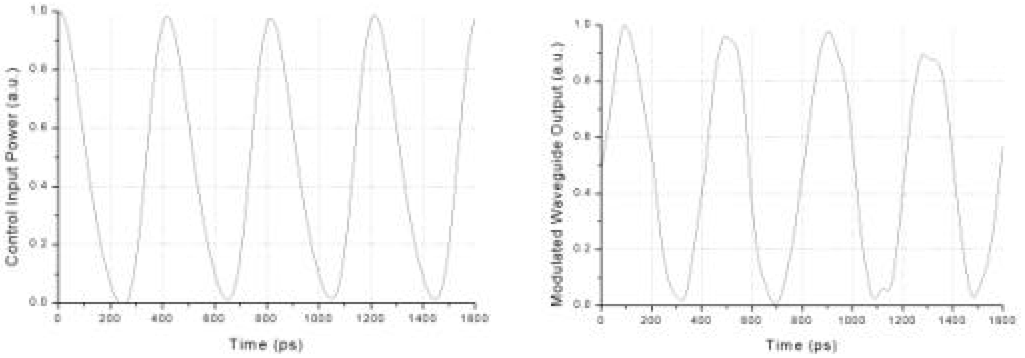

Fig. 2. Left (2a): The output of the control beam laser diode operating at 2.5 GHz. Right (2b): The waveguide signal output modulated by the control beam. The modulation frequency of the output signal (868 nm) is the same as that of the control beam (822 nm), demonstrating wavelength conversion.

In Fig. 2a we show a time snapshot of the control laser diode gain switched at 2.5 GHz and in Fig. 2b the modulated signal out of the waveguide. A reverse bias of 5 V was applied across the device and 1.4 mW average control power was absorbed in the device. We observe that the signal out of the waveguide is modulated at the same frequency as the control. The operating speed of this device is determined by the small RC time constant of the device alone, because the device discharges on to the relatively large pad capacitance faster than the external circuitry is able to respond. The control is completely absent from the output, obviating any need for wavelength filtering.

In this work we demonstrate an optically controlled waveguide switch operating at 2.5 GHz. Based on our previous work on optically controlled optical modulators [4-5], we predict multi-gigabit operation with greater than 10 dB contrast ratio with relatively low control powers. The planar waveguide-surface normal control architecture lends itself to 2D scalability, making this a promising device for future optically switched networks.

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