Novel Electrically Controlled Rapidly Wavelength Selective Photodetection Using MSMs

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Abstract- We demonstrate a novel MSM (metal-semiconductor-metal) based wavelength tunable photodetector with 2.5ns wavelength-switching access time, 20.1dB ON/OFF contrast, discrimination between two 179GHz spaced WDM channels, with ±1.65 V switching voltage.

Rapid wavelength tunings are crucial for modern optical networks to achieve high bandwidth efficiency. Rapidly tunable lasers with a few tens of nanoseconds tuning times have been employed in optical network design [1] for dynamic wavelength allocation. The complementary component, rapidly tunable receivers, would provide further flexibility in network designs. Unfortunately, there is no existing optical wavelength tunable filter with nanosecond scale wavelength-switching access time [2]. In this work, we demonstrate a novel wavelength-selective photodetector, which enables the filtering function in the detector itself, with 2.5ns wavelength-switching access time for switching between two wavelengths.

The device in Fig. 1 is fabricated on a wafer with a 1μm thick undoped GaAs epitaxial active layer on a 0.3μm $Al_{0.85}Ga_{0.15}As$ barrier layer on a semi-insulating GaAs substrate. The fabricated device in Fig. 1 consists of MSM fingers in three regions, left, center and right. The center part, which performs the wavelength switching, comprises two interdigitated biasing electrodes and one comb-like current summing electrode. All three parts have 1μm finger width and spacing. The center part covers a 40μm by 25μm area. Due to its symmetric structure, the I-V characteristic of an ideal MSM photodetector has positive/negative symmetry with respect to bias. When photons hit the MSM device, the direction of the photocurrent depends on the polarity of the voltage bias. This characteristic of MSMs, together with an interference pattern, is used to make the detector wavelength selective. The left side part covers a 20μm by 13μm area. This is used to adjust the overall spectral response by illuminating it by a wavelength independent beam from the signal themselves to achieve a good ON/OFF contrast ratio between the selected and the rejected wavelength. The right side part of the device, which is a dummy structure device to increase the structural symmetry of the detector for symmetrical AC response, is structurally the same as the left side part of the device. This part of the device is biased to ground to avoid contributing any noise to the signal photocurrent.

The key to wavelength selectivity in this device is to form a wavelength dependent interference pattern that lines up with the MSM fingers in the center part of the device and to bias the two electrodes in the center region of the device in Fig. 2 with opposite polarity to respond to specific interference patterns. Methods to set up such a wavelength dependent interference pattern are given in Refs. [2, 3]. The width of the switching part of the device, *w*, as shown in Fig. 2, should be the same as the interference pattern spatial period in this design. In practice, the width of a single interference fringe could be controlled by the incident angle of the two interfered beams to fit the width of the center region of the device.

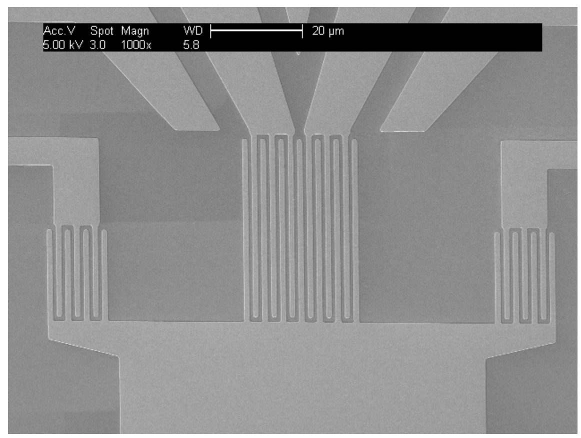

Fig. 1: SEM photograph of the fabricated tunable photodetector with 1μm finger spacing and width.

For WDM applications, since the channel spacing $\Delta\lambda$ is much smaller than λ_0, the width of a single fringe formed by $\lambda_0+\Delta\lambda$ and λ_0 is approximately the same. The interference pattern depends on wavelength, primarily through the spatial phase of the pattern. In particular, if the interference pattern is formed by interfering a beam with a delayed version of itself, the spatial phase of the pattern (i.e., the position of the fringes) moves rapidly with wavelength; hence, the device can be a wavelength sensitive photodetector. To make a detector that can respond to one of two different wavelengths, λ_0 or $\lambda_0+\Delta\lambda$, and reject the other using the electrode pattern of Fig. 2, we both shine the interfering signal beams on the detector, and also shine another controlled portion of the original signal beam (with no interference) on Region III. This additional beam on Region III is adjusted to obtain complete cancellation of the photocurrent from the rejected wavelength. The electrode in Region III is always positively biased, and hence always contributes a positive net photocurrent. If we would like to enable the wavelength shown as the solid line interference pattern (formed by λ_0), while disabling the wavelength shown as the dashed line interference pattern (formed by $\lambda_0+\Delta\lambda$), we positively bias the electrode in Region

I and negatively bias the electrode in Region II. The positive photocurrent from the $\lambda_0+\Delta\lambda$ portion of the beam on Region III cancels the net negative photocurrent that results from the dashed interference pattern (formed by $\lambda_0+\Delta\lambda$), thereby canceling all the photocurrent for the signal beam at $\lambda_0+\Delta\lambda$. If we would like to enable the dashed interference pattern at $\lambda_0+\Delta\lambda$ while disabling the solid interference pattern at λ_0, we can swap the biasing of Regions I and II (while leaving the biasing of Region III always positive), i.e., positively biasing Region II and negatively biasing Region I with now overall cancellation of the net photocurrent for the signal beam at λ_0. Therefore, by determining the biasing pattern applied on electrodes in Region I and II, we can select one wavelength while deactivating the other.

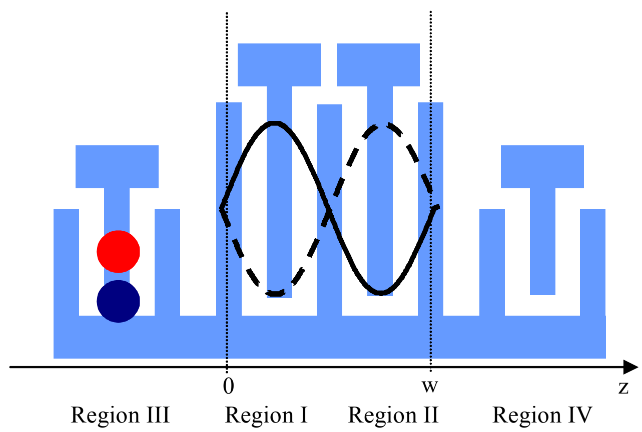

Fig 2: Tunable MSM device, with interference patterns shown as a solid line and a dashed line, for the two wavelength channels. (Note: each interference pattern has a minimum of zero intensity.) Region III is illuminated by another portion of the total signal beam, and is used to adjust the overall spectral response to achieve a good ON/OFF contrast ratio between the selected and rejected wavelengths.

To demonstrate the rapid switching ability of the device in discriminating wavelengths, we used truly differential electrical square waves, toggling every 5 ns between ±1.65 V, to give opposite and alternating bias on the two sets of electrodes in the central region of the device in Fig. 1. The resulting detected photocurrents are shown in Fig. 3 for each of the two chosen wavelengths (806.34nm and 806.77nm). A 2.4 volts dc bias voltage is applied on the left region of the device of Fig. 1, and the optical power fraction on this region is adjusted to give the best rejection of the undesired wavelength (this setting is the same for both of the traces in Fig. 3).

The device is directly mounted on a custom designed printed circuit board (PCB) without any chip package, to eliminate any ringing from parasitic circuit elements of the package. All of the traces on PCB were designed to be coplanar waveguides, connecting to SMA connectors to reduce the unnecessary electrical coupling and energy reflection. We monitor the photocurrent trace of the device in the time domain through a high speed oscilloscope with 50 ohm input impedance and with an internal 1GHz low pass filter. The ON/OFF current contrast ratio is ~20.1dB under this specific DC biasing and interference fringes. This ON/OFF contrast ratio under DC biasing is approximately the same as the ON/OFF contrast ratio in Fig. 3 after the ringing has settled down. The device wavelength switching access time is ~2.5ns, which is limited by packaging issues (bonding wires). A much shorter wavelength switching access time is expected by flip-chip bonding the devices on CMOS electronics to minimize the packaging problems. The channel spacing between the two wavelengths is 179GHz (0.43nm), and this is controlled by the choice of relative delay between the interfering beams. This channel spacing is the minimum available from the Ti-Sapphire laser used, and does not represent any apparent limit for the device.

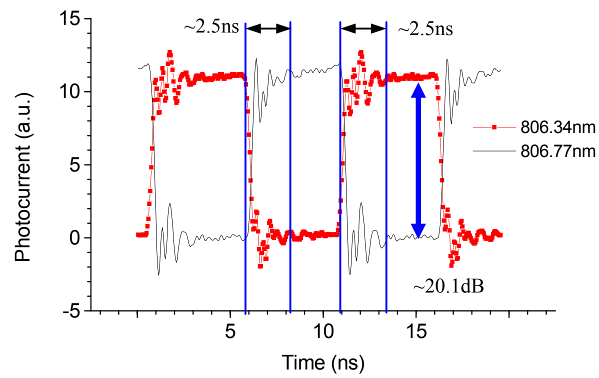

Fig. 3: Photocurrent output of the device as the biasing pattern is changed to select one wavelength or the other. The biasing pattern applied on the device alternates every 5 ns to select between 806.34nm and 806.77nm. The device wavelength switching access time is ~2.5ns and the ON/OFF contrast ratio for selecting one wavelength while deactivating the other is ~20.1dB.

In conclusion, we have experimentally demonstrated a novel electrically controlled wavelength-selective photodetector that can switch between two 179GHz spaced wavelengths with 2.5ns wavelength-switching access time. In addition, this demonstrated photodetector has a ~20.1dB ON/OFF wavelength-selective contrast ratio. The wavelength switching is achieved with a differential input voltage swing of ±1.65 volt. This high-wavelength-resolution, rapidly-tunable photodetector offers new possibilities for reconfigurable wavelength-division optical networks.

References

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