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Novel Electrically Tunable MSM Photodetector for Resolving WDM Channels

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Abstract- We present a novel MSM (metal-semiconductor-metal) based tunable photodetector for discrimination between two wavelengths with a 365GHz channel spacing. If integrated with CMOS circuits, this photodetector has the potential to perform high-speed channel switching in WDM-based systems.

With increasing data traffic load in telecommunications networks, wavelength division multiplexing (WDM) is essential for network capacity and flexibility. Tunable photodetectors that could programmably discriminate the narrowly spaced channels in such WDM system would be very useful for reconfiguring the network. Unfortunately, typical existing tunable filters used for wavelength selection are often mechanically or thermally controlled, leading to slow reconfigurability. In addition, the filters are usually separate components from the photodetectors themselves. Intrinsic wavelength selectivity of the absorption process itself would offer another approach, but that is often restricted to some specific spectral range and can typically not have very narrow channel selectivity. Here, we propose and demonstrate a novel metal-semiconductor-metal (MSM) based tunable photodetector, which enables the filtering function with the detector itself and has the potential to be rapidly electrically tuned simply by changing the MSM finger biasing. This controllable biasing goes beyond previous proposals for fixed multi-finger wavelength detection [1].

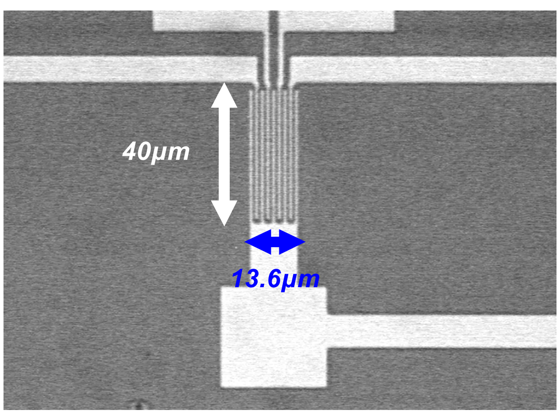

Fig. 1: Photograph of fabricated MSM photodetector with 0.8μm finger spacing and width.

In the present work, we have designed, fabricated, and tested a novel MSM based tunable photodetector. In this demonstration, the detector is fabricated on GaAs (Fig. 1). The device in Fig. 1 consists of a 0.8 μm finger width and spacing interdigitated pattern covering a 40 μm by 13.6 μm area. Due to its symmetric structure, the I-V characteristic of an ideal MSM photodetector has positive/negative symmetry with respect to bias voltage. When photons hit the MSM device, the direction of the photocurrent depends on the polarity of the voltage bias. This characteristic of MSMs is used to make the detector wavelength selective.

The key to wavelength selectivity in this device is to form an interference pattern that lines up with the MSM fingers and to selectively bias the different fingers in the MSM to respond to specific interference patterns. The interference patterns depend on wavelength, and hence the device can be a wavelength sensitive photodetector. If in particular the interference is between a beam and a delayed version of that beam, very fine wavelength discrimination can be performed because the interference pattern changes very rapidly with wavelength. The wavelength resolution of this tunable detector is set by the amount of delay between the beams. For the experiments here, the delayed interference is obtained using a Michelson interferometer with laterally offset beams that are then focused to give the interference pattern. Additional delay in one Michelson arm gives the necessary path difference. Varying the path difference between the two beams controls the resolution, with smaller path difference giving larger detectable channel separation.

To obtain specific wavelength response that can be tuned solely by changes in electrical biasing, the device shown in Fig. 1 can be divided into four regions, I, II, III, IV as shown in Fig. 2. Alternate fingers are each connected to a common virtual ground electrode that will serve to collect the net photocurrent. Different biases can be applied to the other “top” connected fingers. In any given region, if we apply positive voltage bias to the top finger, the photocurrent flows from the top finger to the bottom fingers. On the other hand, the photocurrent flows from the bottom fingers to the top finger if the top finger is negatively biased. By aligning the device with the interference pattern A in Fig. 2, and applying positive biases in regions I and II, and negative biases in regions III and IV, the positive photocurrent from region I cancels the negative photocurrent from region IV, and the positive photocurrent in region II cancels the negative photocurrent in region III, giving no net photocurrent for this condition, and hence rejecting the wavelength that corresponds to this interference pattern. For the same finger biasing pattern, with a different wavelength that gives the interference pattern B, the photocurrent contributed in the first two regions of MSM is going to be larger than the negative photocurrent contributed in region III and IV and there is therefore a net photocurrent through the bottom finger node of the device.

By these kinds of biasing patterns we can configure the device to detect one wavelength and reject another, solely by the biasing of the fingers.
Since the wavelength tuning mechanism is to change the biasing voltage of the MSM fingers, integrating this device with CMOS electronics would allow rapid (e.g., sub-nanosecond) wavelength switching. In addition, the spectral range in which the device can be operated is limited only by the absorption material. For example, fabricated device in Fig. 1 can be operated in entire GaAs material absorption range.

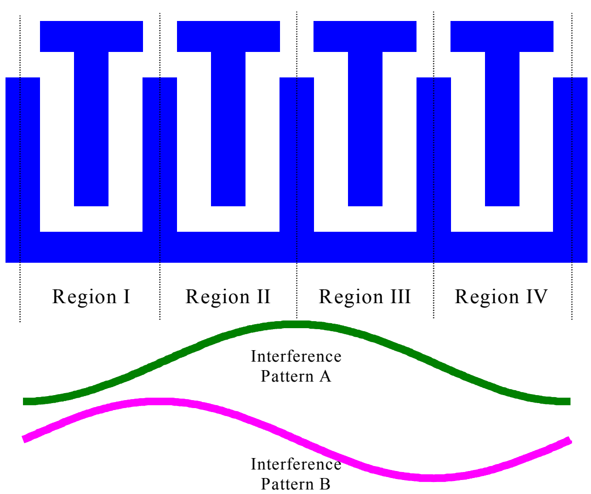

Fig. 2: Tunable MSM device and interference patterns for the two wavelength channels. (Note: each interference pattern has a minimum of zero intensity – the patterns are shifted vertically for clarity.)

Since the two Schottky barriers of the MSM are not exactly identical because of fabrication variations, for our experiments we chose different positive (2.1 volt) and negative (-1.25 volt) biasing of the MSM to nullify out the photocurrent at the rejection wavelength. We obtained net photocurrent as a function of wavelength for one specific biasing pattern as shown in Fig 3, showing, for example, that we could use our device to discriminate 807.54nm from 808.33nm for maximum discrimination. This corresponds to a channel spacing of ~365GHz in 810nm band. In this specific experiment, the actual path difference between the two interfered beams is ~0.72mm. The ideal theoretical response of this device is sinusoidal with wavelength, and we show a fitted sinusoid in Fig. 3. We have been able to resolve channel spacing down to 50GHz when using larger path difference although the results were limited by the laser linewidth and its discontinuous tuning.

We have also demonstrated experimentally that the sensitivity of the device at a specific wavelength can be turned on and off solely by changing the biasing pattern.

In the form shown here, the device has a response that is sinusoidally periodic with wavelength, and allows discrimination only between two such periodic sets of wavelengths. We have also designed structures with more fingers in different parts of the interference pattern that can discriminate multiple different wavelengths with a non-sinusoidal response, and expect to be able to fabricate such structures in the future. We have also developed a general theory for the design of such multiple wavelength tunable detectors.

In conclusion, we have demonstrated a novel electrically tunable MSM photodetector that can discriminate two wavelengths with 365GHz or smaller channel spacing. This device has the potential to be combined with CMOS for rapid detector wavelength tunability.

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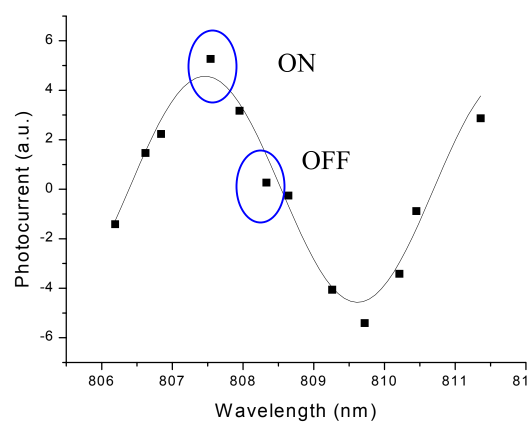

Fig. 3: Experimental results on the response of tunable MSM photodetector for two-wavelength discrimination. An ideal sine curve fit is also shown. For the voltage bias pattern used, the device is sensitive to the wavelength labeled "ON", 807.54 nm, and ignores the wavelength labeled "OFF", 808.33 nm.

References

1. D.A.B.Miller, IEEE J. Quantum Electron. **30**, 732-749 (1994)