High-Speed Nanoscale Metal-Semiconductor-Metal Photodetectors with Terahertz Bandwidth

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***Abstract*—A model for the maximum bandwidth achievable in metal-semiconductor-metal photodetectors is developed and simulated to determine the dimensions required for terahertz bandwidth. The bandwidth is found to exceed 1THz for devices with line pitch less than 100nm.**

I. INTRODUCTION

Metal-semiconductor-metal (MSM) photodetectors are an attractive choice for high-speed optoelectronic applications because of their high bandwidth as well as their ease of fabrication. MSM detectors have demonstrated speeds up to 510GHz [1]. The high bandwidth achievable with MSM photodetectors are due to their inherently lower capacitance compared to other photodetectors such as PIN diodes. Additionally MSM photodetectors require only a single processing step to fabricate.

With the ability to fabricate devices with nanoscale feature sizes the bandwidth of MSM photodetectors can be greatly improved. In order to predict the maximum bandwidth possible of a MSM photodetector we present an analytic model that incorporates both the photo-generated current as well as the capacitive and parasitic elements of the device. We then simulate using this model to determine the maximum achievable bandwidth of a MSM photodetector and the dimensions required to reach this maximum.

II. ANALYTIC MODEL FOR PHOTOCURRENT

A MSM photodetector consists of interdigitated metal lines deposited over a semiconducting material, as shown in Fig. 1. The spacing between the metal fingers in a MSM affects the transit time of the photo-injected carriers, and therefore the overall bandwidth of the device. However as finger spacing decreases to minimize the transit time the device capacitance increases which reduces the bandwidth. Consider a square MSM photodetector with line width w, line spacing L, and area L_{PD}^2. The device is fabricated on a semiconducting substrate such as Si or GaAs. A pulsed laser with pulse width much less than the response time of the photodetector (< 0.5ps) illuminates the device. The photo-generated current $I_{MSM}(t)$ can be found by solving the continuity equation as in [2]. The solution is found by approximating the device in 1-D, which holds as long as the penetration depth δ of the incoming light is much less than the finger spacing L. The solution is an infinite series. The true photo current is the convolution of $I_{MSM}(t)$ with the optical beam, which is a train of Gaussian pluses. Since the pulse width is short compared to the response of the system, it can be approximated accurately as a delta function in time. This means that the optical beam in frequency space is a constant.

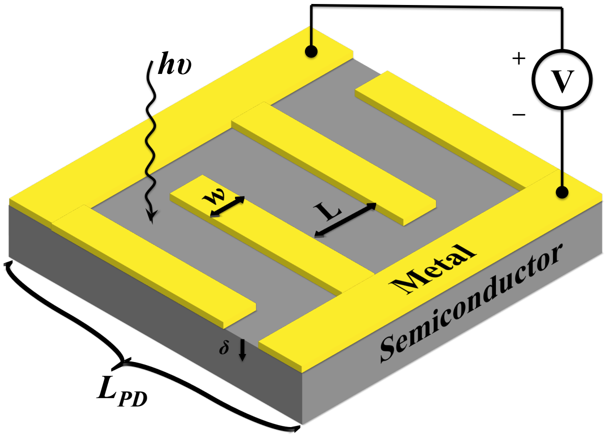

Fig. 1. Physical schematic of MSM photodetector.

The device capacitance, C_{MSM}, is found from the finger spacing as in [3]. C_{MSM} is a function of both the line spacing and width. We then take the Fourier transform of the photocurrent and treat it as a frequency dependent current source. Using the circuit model for the MSM photodetector in Fig. 2 and solving for the output voltage gives us a model for

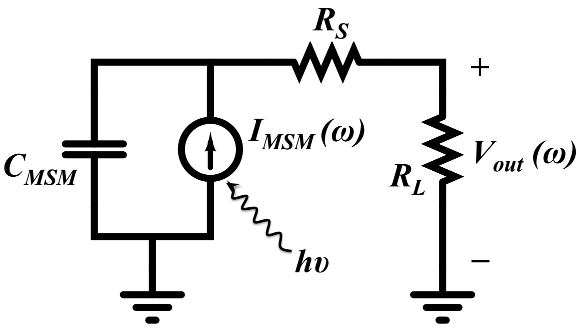

Fig. 2. Circuit model for MSM photodetector.

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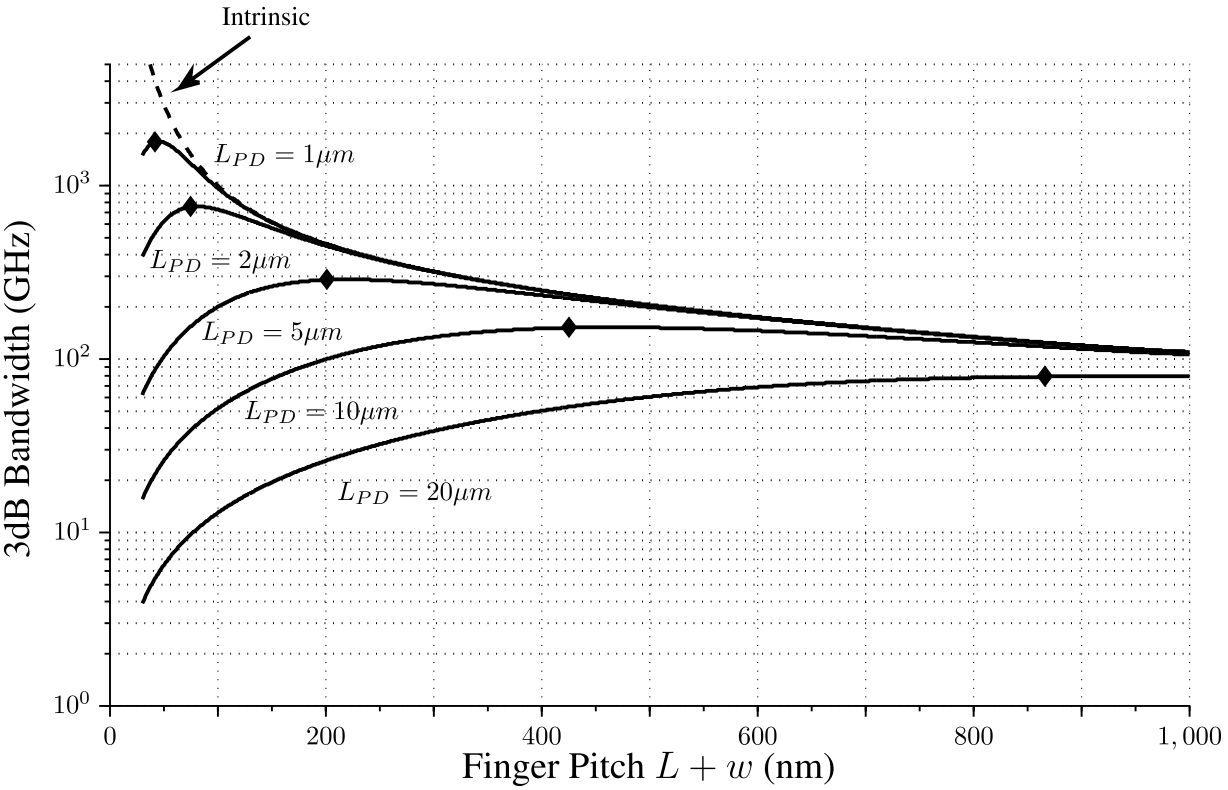

Fig. 3. 3dB bandwidth vs. finger pitch (line spacing plus width) into a 50Ω load for various device sizes in GaAs. Line spacing and width are equal. Saturation velocity of 10^7cm/s used for both electrons and holes. Series resistance from Au bulk resistivity at 200nm thickness. Black dot represents maximum bandwidth point for given device size.

the frequency response of the detector.

III. SIMULATION AND RESULTS

The frequency response is a function of both the device line spacing L and width w (which affects the capacitance, series resistance, and transit time) and the total device size L_{PD}^2 (which affects the total capacitance). We then evaluate this solution over many device sizes to find the -3dB bandwidth, which is shown in Fig. 3. We can see from Fig. 3 that the bandwidth of the detector diverges from the intrinsic transit time bandwidth when the spacing becomes small. The divergence occurs sooner for larger devices, since they have larger total capacitance.

For line pitch ($L + w$) less than 100nm intrinsic speeds exceed 1THz. Actual devices might achieve this speed even sooner due to velocity overshoot. From these results we can infer that the maximum bandwidth for a given device is reduced from the intrinsic bandwidth by a factor of approximately $\frac{1}{\sqrt{2}}$ due to the capacitance. Additionally the optimum line pitch doubles each time the device side length is halved, or the area is quartered. The results of this model show that it is possible to achieve terahertz bandwidth in nanoscale MSM devices.

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