Dual-width Plasmonic Nanogap Gratings electrodes for GaAs Metal-Semiconductor-Metal Photodetectors Enhancement

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Abstract: A dual-width plasmonic nanograting structure with a 5 nm gap has been designed and simulated. Optical enhancement was calculated for the application of improving the performance of metal-semiconductor-metal photodetectors (MSM-PDs).

OCIS codes: (230.5160) Photodetectors; (240.6680) Surface plasmons; (350.2770) Gratings.

Optical properties of certain materials can be changed by modifying the dimensions of various structures at the nanoscale. When an electromagnetic wave is incident on a piece of metal, it will cause an oscillation of free electrons. This oscillation of free electrons is quantized, and the quantization of this plasma oscillation is called a plasmon [1]. The oscillations of electrons can be thought of as waves called surface plasmons, and they can couple with the incident electromagnetic waves, generating a new electromagnetic field, called the local field. The local field can be significantly larger than the incident electric field; thus, significant local optical enhancement (the square of the ratio of local field to incident field) may occur. This phenomenon can be harnessed for several applications, such as photodetectors [2-4], photovoltaics [5,6], bio-sensing [7,8], and surface enhanced Raman spectroscopy (SERS) [9-11].

It has been demonstrated in previous work that optical enhancement in single-width plasmonic structures depends on structure and gap widths [12,13]. Previous work has also shown that a dual-width structure can improve enhancement over a single-width grating [14]. For this new work, we study the plasmonic phenomenon by using plasmonic dual-width gratings to improve the optical enhancement of metallic-semiconductor-metallic photodetectors (MSM-PDs). MSM-PDs have several features, some of which are low cost, low capacitance, low dark currents, and high speeds compared with P-I-N and avalanche photodetectors [15]. These features make MSM-PDs robust candidate devices for developing high-speed optical interconnects, high-sensitivity optical samplers and ultra-wide bandwidth optoelectronic integrated circuit receivers for fiber optic communication systems [16].

Figure 1 illustrates the optical enhancement distribution in the cross-section of on period for different nano-slit plasmonic structures. The design consists of two gold nanostructures (w_1 and w_2), air on top, and GaAs as a substrate on the bottom. Both structures, shown in Fig. 1 (a-b), have the same period, P = 180 nm. However, the difference between them is the gap position, and therefore the lengths of w_1 and w_2. The optical enhancement occurring in the GaAs near the gaps for the dual-width structure (w_1 = 150 nm and w_2 = 20 nm) is 19% greater than that of the single-width structure ($w_1 = w_2$ = 85 nm).

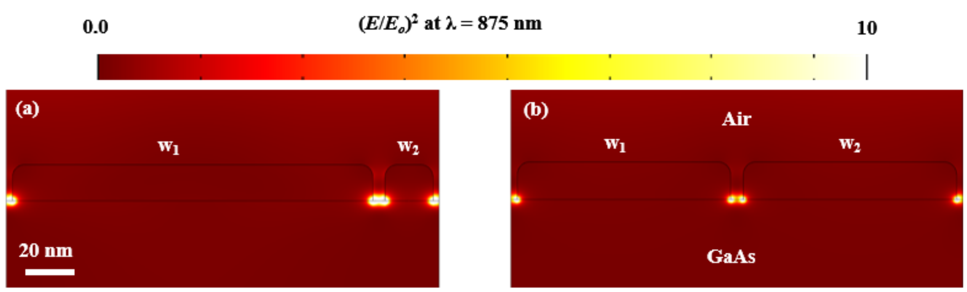

Fig. 1. Optical Enhancement distribution for the same period P = 180 nm, but different wire widths: (a) w_1 = 150 nm, w_2 = 20 nm and (b) $w_1 = w_2$ = 85 nm. The electric field enhancement in (a) is 19% greater than that in (b) in the GaAs near the gap.

Figure 2 depicts a color map of the summation of optical enhancement in the GaAs near the gap when w_1 and w_2 are swept from 20 – 440 nm with a step size of 10 nm. The white dashed line on the diagonal represents the single-width region, whereas points off the diagonal represent the dual-width geometry combinations. The maximum optical enhancement on the diagonal occurs at $w_1 = w_2 = 160$ nm with an enhancement value of (9544) while the maximum enhancement for all geometries occurs at $w_1 = 150$ nm and $w_2 = 20$ nm with a (11282) enhancement value. The results show that the optical enhancement for dual-width is 12% larger than that of the single-width case for $P = 330$ nm. As a result, the dual-width structure can be harnessed for improving the performance of MSM PDs due to its larger optical enhancement compared to single-width. Future work will use these results as well as electrical calculation to optimize the overall photo-current in the device. Once optimize, dual-width structures will be fabricated and tested.

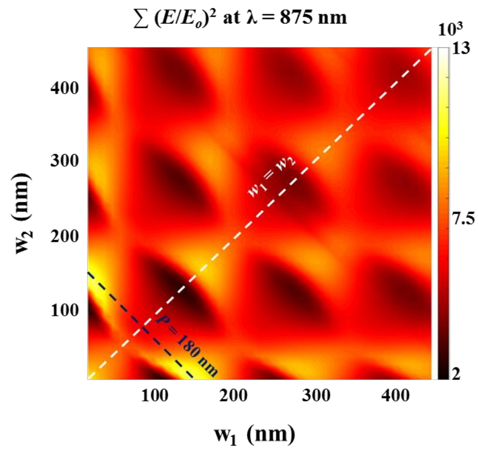

Fig. 2. Color map of the summation of optical enhancement in the GaAs near the gap when the wire widths were swept from 20 nm to 440 nm. It shows that the peak value of the optical enhancement occurs at $w_1 = 150$ nm and $w_2 = 20$ nm. The white dashed line shows the single-width situations and the other points off the diagonal correspond to the dual-width combinations.

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