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Implementation of E-Beam Proximity Effect Correction using linear programming techniques for the fabrication of asymmetric bow-tie antennas

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A B S T R A C T

Asymmetric nano-bow-tie antennas offer the possibility of direct light-to-electrical energy conversion. These nano-antennas are easily integrated with Metal-Insulator-Metal (MIM) tunnel junctions in between the antenna segments for the purpose of coupled signal rectification. The architecture of the tunnel junction together with the antenna size precision require nano-scale patterning accuracy. Electron Beam Lithography (EBL) is used for patterning purposes. In this paper Proximity Effect (PE), a very common resolution problem in EBL, is reduced by a dose modulation technique employing linear programming (LP) algorithms. Production of tightly controlled antenna segment dimensions is achieved in conjunction with a small area tip and a small tunnel junction gap. It is expected that precise control of the gap geometry will enhance detection speed, enabling the utilization of the device for the visible range energy harvest purposes.

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1. Introduction

Advancements in nanometer-scale patterning have enabled new device technologies. Researchers, inspired by radio-frequency antennas, have paid great attention to nano-sized optical antennas for the direct rectification of visible and infrared light. The asymmetric bow-tie optical antenna is an example of such a structure. It offers great advantages, as it is a relatively broad band antenna with low polarization dependence. However, since the architecture of this device requires high patterning accuracy, its fabrication represents a significant obstacle. In this paper, we focus on the fabrication of asymmetric bow-tie optical antennas using E-Beam Lithography (EBL) techniques and we aim to improve the resolution of this technique by correcting Proximity Effects (PE) through dose modulation guided by Linear Programming (LP) algorithms.

Another advantage of the bow-tie structure is the ease with which a rectifying element (a Metal-Insulator-Metal, or MIM diode) can be integrated directly into the antenna. This is shown in Fig. 1. The structure is geometrically asymmetric, as we have shown in other publication, this property of the device contributes to the field enhancement at the junction and yields a higher tunnel current [1]. The conducting parts of the junction are formed by the metal antenna sections and the barrier is the gap in between the antenna parts.

The most important prerequisite for success in infrared (IR) and visible light detection is that the response time must be faster than one cycle of the wave to be detected. The tunneling mechanism does not restrict the device speed because its cut-off frequency is much higher than the wave frequency. However, since the distance between the conductors affects the tunneling probability, it is necessary to keep the junction gap small ($\leqslant$5 nm) for a high rectification efficiency. On the other hand, the equivalent circuit of this device has a junction capacitor across the barrier (C_D) and an antenna resistor (R_A) in series with the junction capacitance. These elements introduce a time constant and define the cut-off frequency limit. It is clear that in order to assure a high cut-off frequency (or, equivalently, a fast response time) a small junction capacitance and a small resistance are required.

2. PEC analysis

2.1. Proximity Effect

As in any antenna design, the dimensional fidelity of the asymmetric bow-tie antenna structure determines the capability of the device. Therefore, we set our objective to maintain the antenna segment dimensions constant while looking for the smallest area and the narrowest gap at the tunnel junction. It should be noted that in this pattern the variation of the distance between the rectangle and the triangle features creates an extra challenge for the realization of the objectives stated

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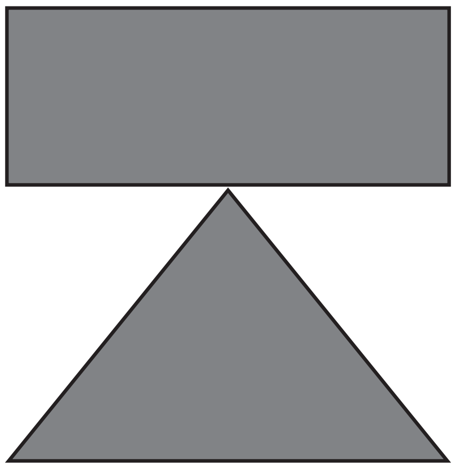

Fig. 1. Schematic of asymmetric bow-tie antenna.

above. We use a Proximity Effect Correction (PEC) approach based on dose modulation to improve pattern resolution. In dose modulation, we control dose in each beam-addressed "pixel" to achieve the best possible image. By "best possible" we mean that the dose contrast factor at each point along a feature boundary must equal or exceed a certain critical value, the total absorbed dose interior to the boundary must be greater than a pre-assigned value and the total absorbed dose exterior to the boundary must be less than a pre-assigned value.

Mathematical modeling of the PE plays a crucial role in developing correction algorithms. The electron beam behavior in the solid is represented by the Point Spread Function (PSF). This function superimposes two Gaussian distributions with different standard deviations, representing, in turn, the backward and forward scattered electrons as shown in Eq. (1) [2].

$$f(r) = \frac{1}{\pi(1+\eta)}\left[\frac{exp\left(-\frac{r^2}{\alpha^2}\right)}{\alpha^2} + \eta\frac{exp\left(-\frac{r^2}{\beta^2}\right)}{\beta^2}\right] \tag{1}$$

where r is the radial distance from the point of incidence, α is the half width of the electron distribution due to forward scattering, β is the half width of the electron distribution due to backward scattering, and η is the ratio of the backward and forward scattered electron distribution.

The absorbed dose profile can best be approximated by the convolution of the PSF and the applied dose matrix as in Eq. (2).

$$E(x,y) = G(x,y) \otimes P(x,y) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} G(i,j)P(x-i,y-j)\,di\,dj \tag{2}$$

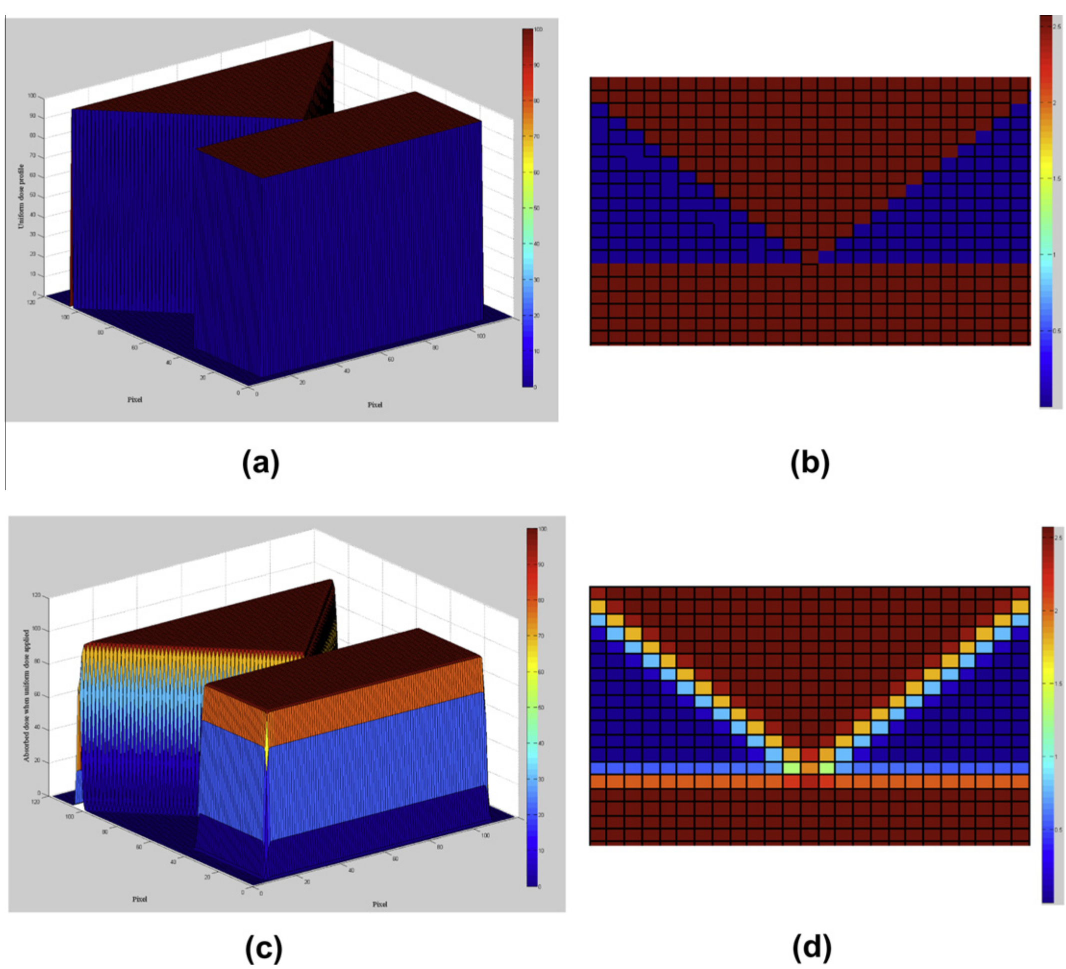

Fig. 2. Simulation results without PEC: (a) uniform dose profile; (b) top view of (a) zoomed at the junction; (c) absorbed dose profile when uniform dose applied; (d) top view of (c) zoomed at the junction.