Two-Dimensional Device Simulation of the InGaAs/InP Avalanche Photodiodes

1. Introduction

The high gain, and high gain-bandwidth product of the avalanche photodiodes is one of the key device for the long distance optical communication systems. For the 0.92-1.65um wavelength range, the narrow bandgap materials, like InGaAs(0.77eV), are used as the absorption medium. And the breakdown location is a major issue to design of the APD's. In order for the device to operate with high gain and low noise[1], the design of the guard ring to suppress edge breakdown is important.

The object of this article is to get the multiplication[2], the leakage current under the dark and the illuminated current[3] was simulated. And the other important factor of the cut-off frequency calculated by the numerical device simulator ***ATLAS***.

2. Device Structure and Models

In order to simulate of the APD's, the thickness and doping level used conventional APD device. The dark current and illuminated current is very depend on the absorbed layer and the doping profile. And the multiplication layer thickness is the very key parameter of the breakdown voltage and position of the avalanche. Here the simple APD's structure showed with guard ring as Figure 1.

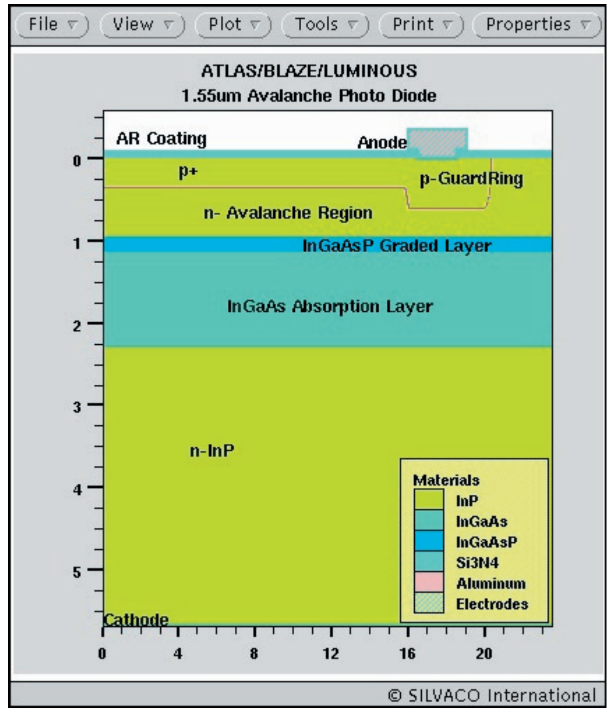

Figure 1. Cross-sectional view of the simulated APD.

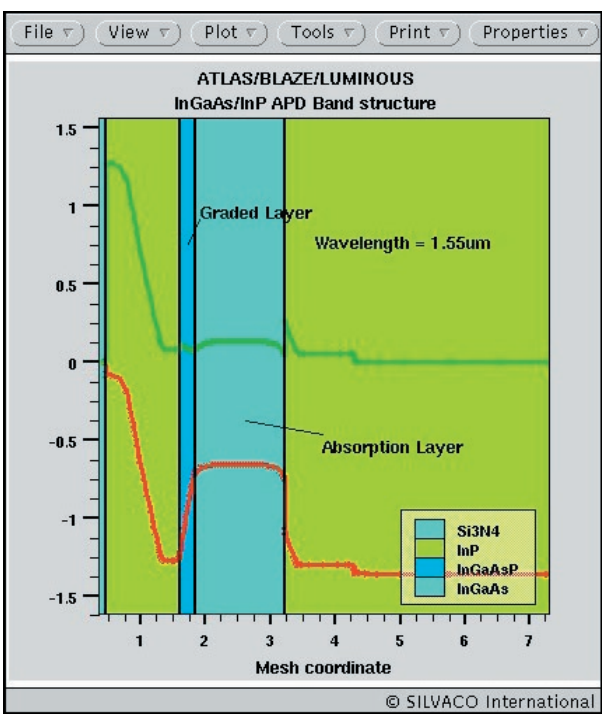

Figure 2. The Band structure of the APD.

A thick InGaAs absorption layer with very low donor type is on the InP substrate with the InP buffered layer. The speed of the APD is very depend on the thickness of the absorption layer. This is due to the reduction in transit time when this absorption layer is reduced. And in order to reduce the charge build-up at the heterojunction interface a graded layer is introduced between the InP and InGaAs absorption layer.

To simulate the avalanche photodiodes, the generation rate due to impact ionization must be calculated.

The general impact ionization process is described by

$$G = \alpha_n \left|\vec{J}\right|_n + \alpha_p \left|\vec{J}\right|_p$$

here, G is the local generation rate of electron-hole pairs, $\alpha_n \alpha_p$ are the ionization coefficient for the electron and hole, $J_n J_p$ are their current density.

In ***Blaze/ATLAS***, the impact ionization rate included with the self-consistantly in basic equation and material parameters[4]. For the purpose of numerical simulation, the parameters for the InP and InGaAs was given in Table I. And the other basical material parameters are integrated in ***Blaze/ATLAS*** depend on the mole fraction. Figure 2 shows the Band structure of this APD.

Parameter	Units	InGaAs	InP
Electron Auger Coeff	cm6/s	7.0e-29	9.0e-31
Hole Auger Coeff	cm6/s	7.0e-29	9.0e-31
Electron SRH lifetime	sec	8.0e-8	6.0e-12
Hole SRH lifetime	sec	8.0e-8	6.0e-12
Radiative Recombination Rate Coeff	cm3/s	9.6e-11	1.2e-10
Electron Impact Ionization	1/cm	5.15e7	1.0e7
Electron Critical Field V/cm		1.95e6	3.45e6
Hole Impact Ionization	1/cm	9.69e7	9.36e6
Hole Critical Field	V/cm	2.27e6	2.78e6
Light absorption Coeff	1/cm	8000	0

Table I. List of the Material Parameters used for the simulation

And the influence of the applied bias with illuminated condition, the opto-generation rate must be calculated. The ***Luminous*** is a general purpose of ray tracing and light absorption program integrated into the ***ATLAS***.

$$G = \alpha_n \left|\vec{J}\right|_n + \alpha_p \left|\vec{J}\right|_p$$

here, the η_0 is the internal quantum efficiency, P* contains the cumulative effects of reflection, transmission, and loss due to absorption, λ is the wavelength of the illuminated light, h is Planck's constant, c is the speed of light, α is the absorption coefficient.

The light into the APD can set the gaussian form as like the beam from the optical fiber. And the C-Interpreter could make sure the user's unique absorption model depend on the illuminated wavelength. In Figure 3 under the metal has high absorption coeff, so the photogeneration rate close to be zero.

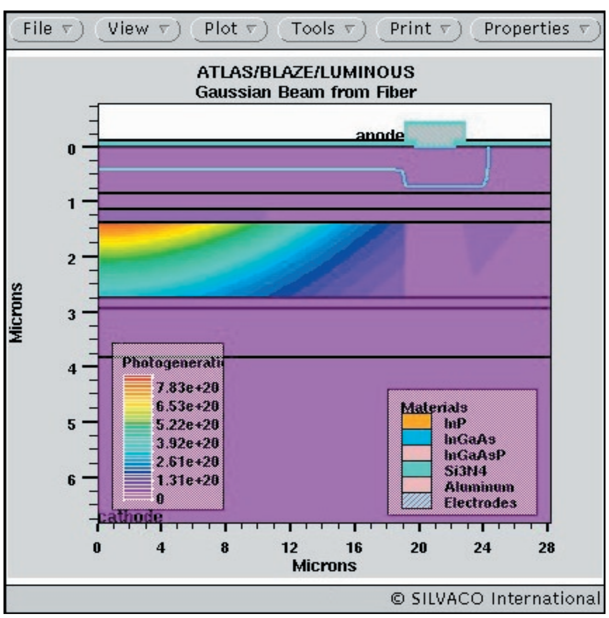

Figure 3. The gaussian beam form like outcoupling from optical fiber.

3. Simulation Results and Discussion

The dark current and illuminated current versus bias voltage is shown in Figure 4. As the Figure 4, there are 3 phase of operation.

In phase I, the current is due to thermally excited carriers in the InP, and for the illuminated case, the collection of generated is zero.

In Phase II, the charge sheet has been fully depleted and the device operates like to p-i-n photodetector. Under this condition, the carriers are not transported to multiplication layers in the high field. And for the illuminated case, the depletion layer still under the Graded layers, so the absorption effect is very low.

In phase III, the device operates as an APD. The carriers generated within the InGaAs absorption layer with photogeneration can drift into the high field multiplication region, so an internal gain mechanism was provided

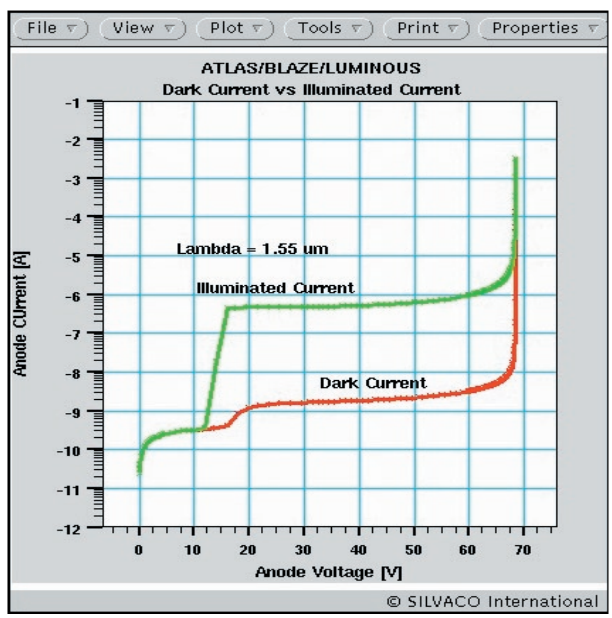

Figure 4. Typical I-V plot of the dark and illuminated current.

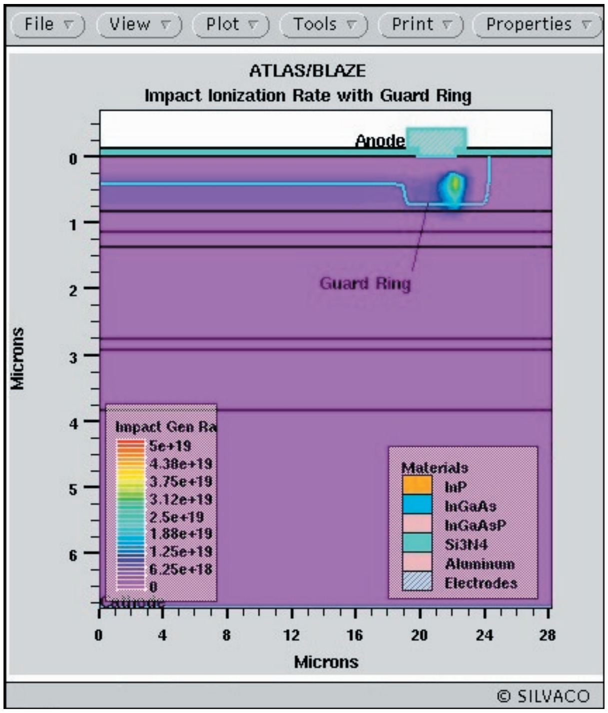

Figure 5. Impact Ionization rate distribution due to the Electric field.

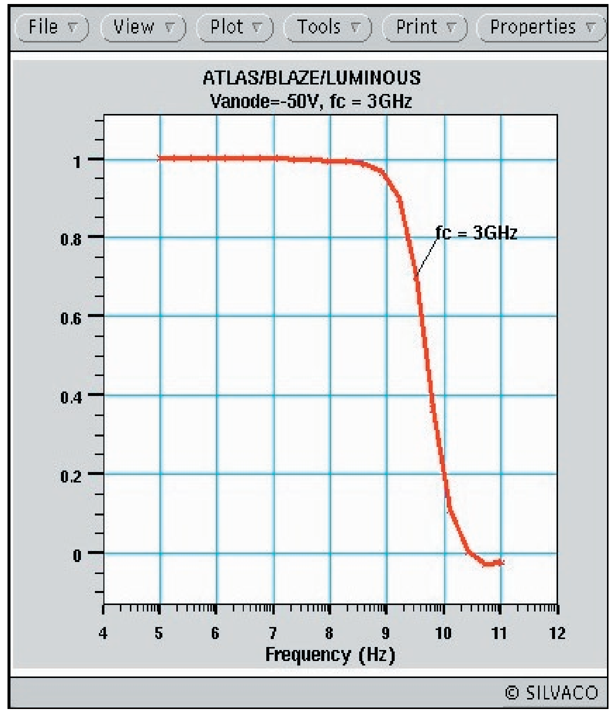

Figure 6. Frequency vs Normalized modulated output.

with the impact ionization. In Figure 5, the distribution of the impact ionization rate shows where the maximum electric field is high on the multiplication layer.

Finally, the AC response of the APD was calculated with small signal analysis of the illuminated light. The Figure 6 shows the 3 GHz cut-off frequency by the ***Luminous/ATLAS***. The plot of the 3dB bandwidth could make the collect the cut-off frequency each Anode bias point.

4. Conclusion

The InGaAs Avalanche Photodiodes has been successfully simulated within the ***Luminous/ATLAS*** for the DC analysis and AC analysis in this article. And the dark current and illuminated current was shown under the reverse voltage. The ATLAS is linked seamless the drift diffusion to impact ionization and photogeneration.

Reference

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