Hydrogen Passivation of Photodiodes

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Abstract:

The objective of this project was to investigate the effects that hydrogen passivation has on the dark current of p-i-n InGaAs/InP photodiodes. The p-i-n InGaAs/InP photodiodes were grown using Molecular Beam Epitaxy (MBE); their I-V characteristics at room temperature were obtained using a micromanipulator and a HP 4156B Semiconductor Parameter Analyzer.

Our results show that the dark current can be reduced by an average factor of 1.2 under optimized conditions.

Introduction:

Photodiodes are two terminal devices designed to respond to photon absorption. One of the important aspects of these devices is their bandgap, which determines the wavelength of the absorbed photon. The smaller the band-gap is, the longer wavelength it is able to detect.

In the MBE group at The University of Texas at Austin, photodiodes are being pursed for use in mid-infrared (MWIR) detection and single photon counting. An important shared aspect of devices for these applications is that they both need a low dark current.

When a bias is applied to a photodetector, a current is generated, the current can be dark current (output current under no radiant power/background) or photocurrent (output current under radiant power). The photocurrent is directly related to the number of photons absorbed. Thus a low dark current is needed to detect a small number of incoming photons. Because of properties in the semiconductor, traps are created in the semiconductor. The more traps there are, the higher the dark current is, regardless of the band-gap.

The main focus of the project, involved hydrogen passivation of the samples; that is, exposing the photo-diode to atomic hydrogen (created via a H_2 plasma) to passivate the electron traps, or defects. This process would ultimately make the dark current be as small as possible.

Various methods for surface passivation of III-V semi-conductor devices exist, including hydrogen plasma treatment and deposition of dielectric films such as silicon nitride, silicon dioxide, and polyamide. Although the effects of hydrogen passivation have been studied in other III-V compound devices [1], this has not been done with InGaAs/InP photodiodes.

Procedure:

The samples were fabricated into mesas by standard photolithography, chemical wet etching (1 phosphoric acid : 1 Hydrogen Peroxide : 10 water) , evaporation and lift-off processes. The top (p) contacts were made with Cr-Au, and the bottom (n) contacts were made with Au-Ge-Ni-Au to obtain circular devices ranging from 40 μm to 160 μm in diameter.

Hydrogen Passivation:

To create the atomic hydrogen, the samples were exposed to a hydrogen plasma created in a Reactive Ion Etcher (RIE). In the Phase I experiments, all samples were exposed to the plasma for ten minutes while other parameters (power, hydrogen flow rate, and pressure) were varied. The values tried are shown in Table 1. Afterwards, when the best values were obtained, the only variable left to experiment with was time. This was varied in the Phase II experiments.

Results and Conclusions:

The first few samples were lost because after

RECIPES TRIED			
Recipe Try	Pressure (mTorr)	Flowrate (sccm)	Power (W)
III	200	100	90
IV	200	100	25
V	200	10	25
VI	200	100	25
VII	500	100	25
VIII	44	100	25
IX	44	100	100
X	44	5	100

Table 1

getting the I-V characteristics, when it came time to give them H plasma treatment, the samples came out covered with a kind of oxide which made retaking accurate measurements impossible. We realized that this unknown coating was a residue of an InGa eutectic smeared on the back of the samples; this somehow reacted with the hydrogen plasma and created said coat on top of the device.

The process was repeated on devices without InGa eutectic. The best recipe found for the hydrogen plasma was:

- A power of 100W.
- A hydrogen flow rate of 5 sccm,
- A chamber pressure of 44 mTorr.

A maximum power of 100W was applied because we feared stronger power would ionize too much the particles and burn the device, since after the process was done, in one of the runs with more contamination, it looked as if a small explosion had occurred inside the chamber around the device.

The average factor of increase in dark current for all Phase I samples is shown in Figure 1. This is defined as the average difference between the dark current values of the devices before and after the processes, taken from an average of five devices per sample. The effects of time on recipes VIII and X are shown in Figure 2 and Figure 3, respectively.

After longer exposure to recipe X, a coating of contaminants formed on top of the device. The solution to this problem was to give a longer oxygen clean to the chamber before running the process. Even though the last treatment did decrease the dark current, and as an added bonus it increased the photocurrent by an average factor of 1.2, a light coat of contaminant still formed on top of the device.

Summary and Future Work:

Different hydrogen plasma formulas were tried to find out if a treatment would passivate the defects, reducing the dark current of InGaAs photodiodes; satisfactory results were obtained for two different recipes at the times listed.

Further research is needed to explain the reaction of the InGaAs samples to the different hydrogen plasma treatments, as well as the InGa eutectic reaction the hydrogen. In addition, more work is needed to investigate other cleaning techniques for the chamber and devices before the process, and the different effects this variations might have since the experiments suggest that cleanliness is key.

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References:

[1] M. Bissiri, G. Baldassarri Ho ger von Ho gersthal, A. Polimeni, V. Gaspari, F. Ranalli, and M. Capizzi, Phys. Rev. B 65, 235210 (2002).

[2] D. G. Yu, C.-H. Chen, A. L. Holmes Jr., S. P. DenBaars and E. L. Hu, JVST B. 15(6), Nov/Dec 1997.

[3] M. Schvartzman, V. Sidorov D. Ritter and Y. Paz, JVST B. 21(1), Jan/Feb 2003.

[4] Design, Fabrication and Characterization of Quantum Dot Infrared Photodetectors, Zhengmao Ye, Ph.D, The University of Texas at Austin, 2003, Doctoral Dissertation.

Figure 1

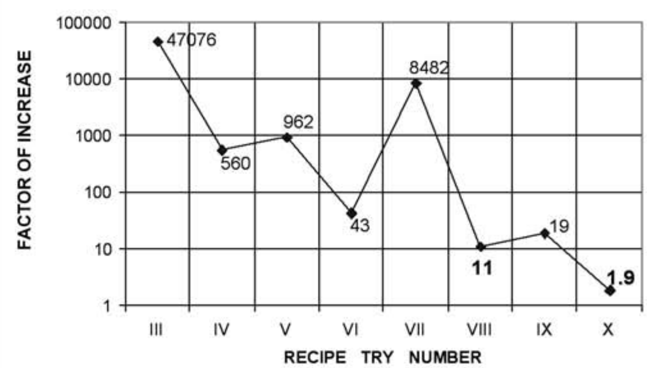

Figure 2

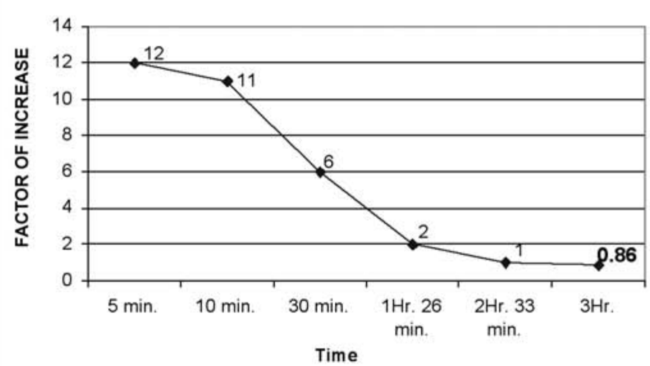

Figure 3