ML3 (Contributed Oral)
11:15 AM – 11:30 AM

Extended Wavelength InGaAs-Based Avalanche Photodiodes for Single Photon Counting Applications

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Introduction

From the perspective of performance, reliability, and cost, the most practical photodetectors available today with single photon sensitivity between 1.0 and 1.6 μm wavelengths is the InGaAs/InP single photon avalanche diode (SPAD)[1]. These detectors based on separated absorption charge multiplication (SACM) APDs have low dark count rate (DCR) and high photon detection efficiency (PDE). The decrease in DCR allows the dead time for SPADs to be reduced, increasing the photon counting rates. Negative feedback APDs (NFADs) have also gained recent attention due to its simple bias circuitry and reduced dead time by monolithically integrating a thin-film feedback resistor on a SPAD[2].

For applications such as free space optical communications and short-wave infrared (SWIR) imaging applications, it is desirable to extend the wavelength beyond 1.7um to benefit from lower atmospheric scintillation and attenuation. It is non-trivial to integrate graded-buffer extended InGaAs absorber layers with InP-based SACM APD structures as it would require a redesign of the of the multiplier, charge and grading layers based on the new graded lattice parameters. Besides, the dislocation defects emanating from the absorber region would impact both performance and yield.

In recent years, research on Type II super lattice (SL) structures consisting of alternating thin layers of III-V semiconductor compounds has shown considerable promise for creating photosensitive absorbers with optical properties dictated by “bandgap engineering” as opposed to relying on intrinsic materials properties. One of the best known examples of such a structure, the binary/binary InAs/GaSb SL has gained much attraction and has demonstrated absorption of mid and long-wave infrared wavelengths[3]. Recent interest has increased in Type-II SL absorber regions based on alternating layers of InGaAs and GaAsSb that is compatible with InP substrates[4,5]. This lattice matched approach enables the leverage of multiplication, charge layer and grading layers employed on commercial SPADs developed over the past decade. In addition, compatibility with InP substrates allows the ability to leverage advances in InP-based epi-growth and mature wafer foundry capabilities for processing InP-based structures.

In this paper we present our design and characterization results on SPADs and NFADs with InGaAs/GaAsSb Type II SL absorption regions.

Device Design

The mesa-type InGaAs/GaAsSb Type II SL based NFAD cross-section is shown in Figure 1.

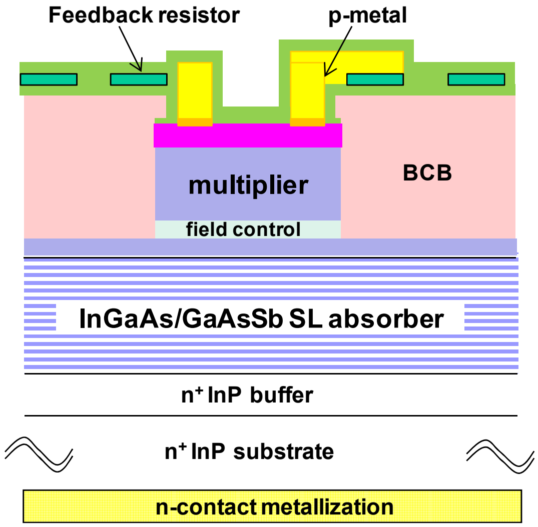

Figure 1. Cross-section of NFAD device.

The following epi-layers were grown on the InP substrate: a 1μm n-type doped InP buffer layer,

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a ~1μm InGaAs/GaAsSb Type II absorber layer (100 repetitions), InGaAsP grading layer, a InP field control (charge) layer, and an intrinsic InP multiplication region, followed by a p+ doped InP cap layer. The mesa definition process etches through the InP multiplication and field control layers of the APD structure and defines the active region of the devices. In this design, the smaller bandgap Type II superlattice layer remains unetched. This shallow-etched mesa geometry is passivated by BCB. The thin film resistor of NFAD devices is deposited on top of the BCB layer in a concentric ring pattern around the device mesa.

Characterization Results

We packaged SPADs and NFADs in TO-46 cans to perform device characterization at reduced temperature. We placed the packages inside a temperature chamber with low-noise BNC cables connecting the device terminals to a Keithley 236 source measurement unit. I-V characteristics were measured after stabilizing the oven temperature at -40 °C. Figure 2 illustrates the dark current vs. reverse bias behavior of four SPADs with a 30 μm mesa diameter. The very low variation among these devices suggests excellent surface passivation of the shallow etched mesa by BCB as well as good uniformity of the epitaxial growth across the wafer.

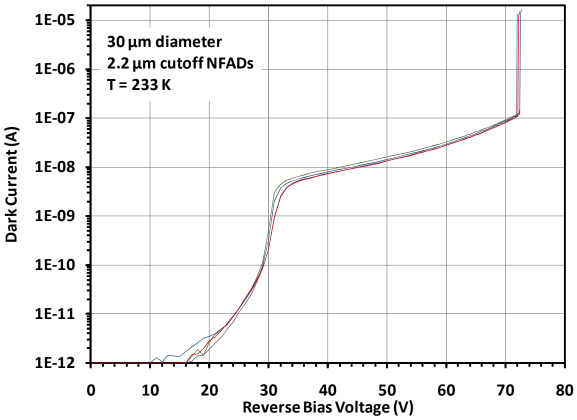

Figure 2. Reverse bias dark current characteristics of four packaged SPAD devices.

We then characterized the dark count rate of the ~2.4 μm cut-off SPADs using PLI's commercial photon counting instrumentation. The TO-46 packaged devices were again operated at -40 °C to carry out these tests. Standard gated quenching operation at a 5 MHz gate repetition rate was used to determine the dark count rate on two devices as a function of excess bias as shown in Figure 3. The performance shown is very encouraging for an extended wavelength SPAD, and demonstrates that these devices can be operated reliably above breakdown (in Geiger-mode). We are currently in the process of coupling optical fibers to packaged SPADs to enable measurement of the PDE.

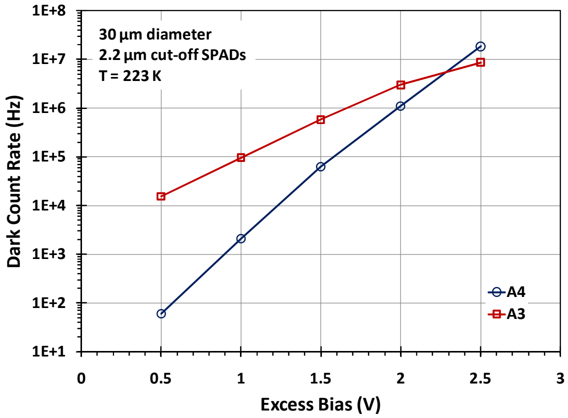

Figure 3. Dark count rate measured for two 2.2μm cut-off SPADs at -40^{o}C.

Conclusion

We present our design and characterization on SPADs and NFADs with InGaAs/GaAsSb Type II SL absorber regions on InP substrates with extended wavelength detection up to 2.4μm wavelengths for single photon counting applications. Packaged devices showed very low variation at -40^{o}C, with ~100nA dark current at 2 volts below breakdown voltage. The measured DCR was 10^6 Hz at 2 volts excess bias at 223K.

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