Separate Absorption, Charge, and Multiplication Avalanche Photodiodes With InGaAs/GaAsSb Type-II Superlattices Grown by Molecular Beam Epitaxy.

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Abstract

Avalanche photodiodes (APDs) can be used in remote sensing applications, such as atmospheric greenhouse gas monitoring, free-space optical communications, and medical diagnostics, including the extended short-wavelength infrared (eSWIR) range between 1.3 μm and 2.5 μm. APDs have internal multiplication characteristics that allow them to detect weak signals. However, traditional *p-i-n* structure APDs, commonly used for longer infrared wavelengths (1.55 – 3.4 μm), can be performance-limited by the high dark currents due to band-to-band tunneling when subject to high electric fields. A separate absorption, charge, and multiplication (SACM) structure can be employed to improve their performance. The SACM structure decouples the absorption region from the multiplication regions, maintaining the absorber region below the tunneling threshold while keeping a high electric field only in the multiplier. In this work, we designed, grew, and fabricated an eSWIR SACM APD. The epitaxial layers grown by molecular beam epitaxy consist of a 5 nm-$In_{0.53}Ga_{0.47}As$/5 nm-$GaAs_{0.51}Sb_{0.49}$(InGaAs/GaAsSb) type-II superlattice (SL) absorber and 1000 nm-thick $Al_{0.85}Ga_{0.15}AsSb$ (AlGaAsSb) multiplier on a InP substrate. The development of the SL involved the growth of InGaAs with a growth rate of 1 μm/hr and a V/III beam equivalent pressure (BEP) ratio of ~10, along with GaAsSb grown at a rate of 0.47 μm/hr and a V/III BEP ratio of ~20. Both were grown at a temperature of 470 °C, as measured by the Bandit system. Meanwhile, AlGaAsSb was grown at a rate of 0.6 μm/hr and a temperature of 500 °C. The X-ray diffraction (XRD) result of our devices is presented in Figure 1, which reveals a mismatch of -440 arcsec and -260 arcsec for AlGaAsSb and SL, respectively. The period of the SL was calculated from a distance between the satellite peaks, determined to be 9.75 nm. These devices have a cut-off wavelength of 2.4 μm, a gain of up to 60 at room temperature, and a resulting quantum efficiency of 600% at 2 μm. as shown in Figure 3. Furthermore, the excess noise factor of our AlGaAsSb-based SACM APD stays below 2.2, up to a gain of 30. This value is considerably lower than competing technologies, with 2 times lower than InAlAs-based SACM APD and 1.2 times lower than InAlAsSb SACM APD on GaSb at the gain of 10.

These results demonstrate the potential of AlGaAsSb-based SACM APDs with InGaAs/GaAsSb SLs for various eSWIR detection applications and provide insight into the design and fabrication of SACM APDs with good noise and sensitivity characteristics, making them suitable for a range of remote sensing applications in the eSWIR range. These results have significant implications for developing highly sensitive and low-noise APDs for use in various applications.

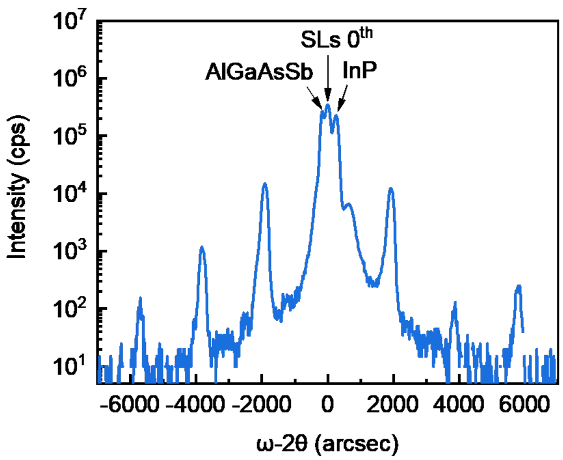

Figure 1. The XRD result of our SACM APDs with AlGaAsSb multiplier and InGaAs/GaAsSb SL on the InP substrate.

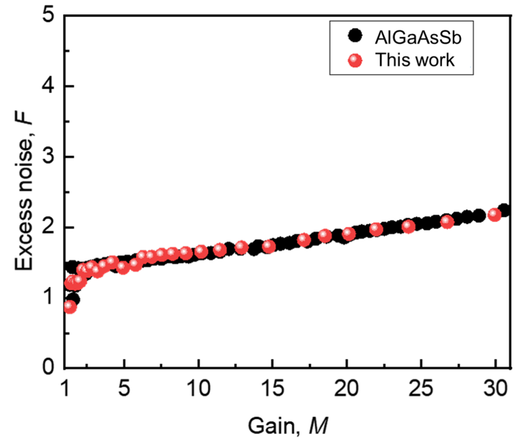

Figure 2. Excess noise as a function of gain for the SACM APD described in this work, compared with a 1000-nm thick AlGaAsSb *p-i-n* APD.

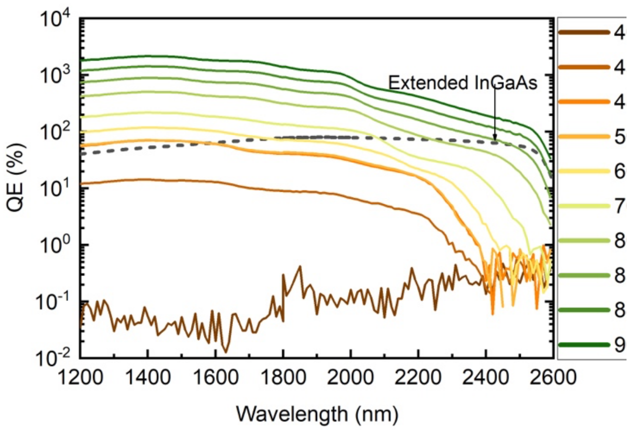

Figure 1. External quantum efficiency of an eSWIR AlGaAsSb-based SACM APDs with InGaAs/GaAsSb SL absorber at various reverse biases. The dotted line is for a commercial extended InGaAs photodiode with a cut-off wavelength of 2.6 μm.

ACKNOWLEDGMENTS

This work was supported by the Advanced Component Technology (ACT) program of NASA's Earth Science Technology Office (ESTO) under Grant No. 80NSSC21K0613.