Band engineering, growth and characteristics of type-II InAs/GaSb superlattice-based detectors

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We report on band engineering, growth and device performance of infrared photodetectors based on type II InAs/Ga(In)Sb strain layer superlattices (SLs) using the complementary barrier infrared detector (CBIRD) design. The unipolar barriers on either side of the absorber in the CBIRD design in combination with the type-II InAs/GaSb superlattice material system are expected to outperform traditional III-V LWIR imaging technologies and offer significant advantages over the conventional II-VI material based FPAs. The innovative design of CBIRDS, barrier and band offset engineering , low defect density material growth, and robust fabrication processes have resulted in the development of high performance long wave infrared (LWIR) focal plane arrays at JPL.

The type-II InAs/GaSb superlattice (SL) system has been investigated as a promising system for infrared (IR) detection ever since it was proposed by Smith and Mailhiot [1] over three decades ago. In SL structures, the energy difference between the electron miniband and the first heavy-hole state at the Brillouin zone center defines the electronic bandgap; therefore the bandgap can be tailored by varying the thickness of the two constituent materials. Thus, the type-II InAs/GaSb SL cut-off wavelength can be tuned to span a broad spectrum from mid-infrared (MIR) to very long-infrared (VLIR) (3 μm <λ< 30 μm) by changing the InAs and GaSb layer thicknesses.

Furthermore, the extra degrees of freedom in designing the bandstructure of the SL can be explored to enhance the performance of the detectors fabricated from such an absorber material. Tunneling currents in SLs are reduced due to a larger electron effective mass. Also, large splitting between heavy-hole and light-hole valence sub-bands due to strain in the SLs contributes to the suppression of Auger recombination. Moreover, the band structure of the SLs can be engineered to enhance carrier lifetimes [2] and reduce noise at higher temperatures [3]. SL based IR detectors have demonstrated high quantum efficiency [4], high-temperature operation [5] and are suitable for incorporation in focal plane arrays by tapping into the mature III–V based growth [6] and fabrication processes [7].

Despite the above advantages there still exists challenges with type-II InAs/GaSb SL devices regarding the suppression of band-to-band and defect-assisted tunneling currents as well as surface leakage currents. More recently, barrier infrared detector (BIRD) concepts such as the nBn [8] device design have shown promising results to be superior to superlattices in the MWIR region. We have demonstrated a new design, so-called the complementary barrier infrared detector (CBIRD) [9] which enables high LWIR performance. The CBIRD design (shown in figure 1) incorporates two unipolar barriers – one on each side of the superlattice absorber layer.

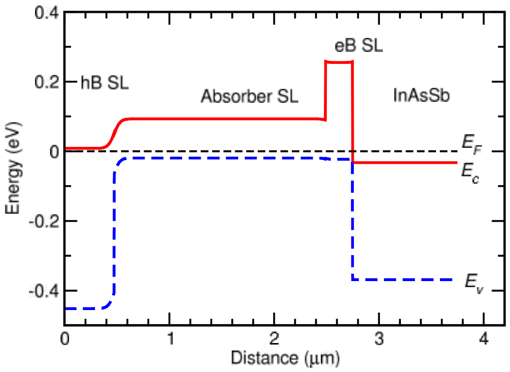

Figure 1: The energy band diagram of the complementary barrier infrared detector structure, showing the conduction and valenceband edges and the Fermi level under zero bias.

In this paper/talk we will illustrate that by using the advantage of band engineering associated with InAs/GaSb/AlSb superlatticesa, advantages of heterostructure designs, and a controlled and optimized material growth process high performance infrared detectors and focal plane arrays are achieved.
Single element detectors with square mesas of area 200×200 µm^2 from a well optimized CBIRD structure were fabricated using standard optical lithography, wet chemical etching and evaporation of top and bottom Ti/Pt/Au ohmic contacts. Current voltage *(I-V)* characteristics as well as quantum efficiency of SL detectors were measured at 77 K. As figure 2 (a) indicates the current density is less than $j < 1\times10^{-5}$ A/cm^2 at applied biases up to $Vb = 0.18$ V and QE of 30 % (figure 2b) was achieved at applied bias of 100 mV. Both of these values show high performance longwave infrared detector.

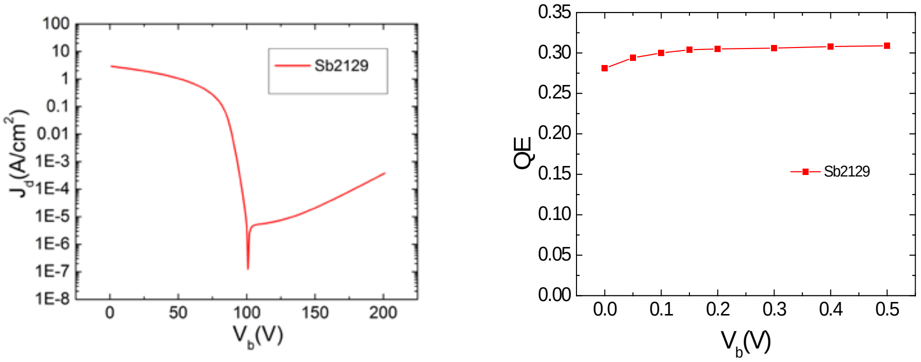

Figure 2: (a)Dark current density,(b) QE versus turn on bias of the LWIR CBIRD structure at 77 K

The antimonide material system is relatively robust and has the potential for good manufacturability. The versatility of the material system, with the availability of three different types of band offsets, provides great flexibility in device design. Complementary barrier design has theoretically shown reduction in band to band tunneling, generation-recombination and diffusion dark currents. The flexibility of the SL materials system, the elegant design of barrier infrared detectors (BIRDs), as well as material growth optimization offer great potential both for higher-operating temperature and low background applications. In this work we demonstrated the use of CBIRD barrier design to improve the detector performance of longwave InAs/GaSb superlattice detectors.

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1. References

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