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Superlattices see in the dark

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Sandwich structures make IR cameras that provide high-quality IR images, detecting even minuscule temperature differences within a tenth of a millisecond.

According to Planck's blackbody law, IR imaging can be performed without an additional light source, such as the sun. The IR radiation from any object that is near room temperature or hotter can be collected—using thermography or IR imaging—to reveal intrinsic temperature-related properties. Today's IR technology improves many processes, including night vision and target tracking for homeland security and defense, non-destructive failure detection in industry, chemical sensing in medicine, and free-space communication.

Several devices already take advantage of the unique properties of this part of the electromagnetic spectrum. In IR-photon detectors, for example, the absorbing material transforms incoming photons into electrical charges that increase the current flowing through the detector. Measuring the current quantifies the infrared radiation. These devices are fast and sensitive, but they must operate at a low temperature. Also, the leading material platform, mercury cadmium telluride (HgCdTe), lacks the uniformity required for large cameras, and the fabricated imagers are very expensive.

One of the most promising candidates to replace HgCdTe is type-II indium arsenide (InAs)/gallium antimonide (GaSb) superlattices.[1] Growing alternate layers of nanometer-thick InAs and GaSb forms a superlattice (see Figure 1). When sandwiched between two GaSb layers, an InAs layer behaves as a quantum well for electrons, and the GaSb layers act as quantum wells for holes. The repetition of these layers creates a band structure similar to that in common bulk semiconductors, but with a small energy gap corresponding to wavelengths ranging from 3–32μm. Also like bulk semiconductors, a type-II superlattice exhibits much stronger optical absorption than other low-dimensional systems, such as quantum dots and quantum wells.

Six years ago, the Center for Quantum Devices at Northwestern University fabricated the first IR camera based on this material by bonding an array of sensors to a silicon chip that performed signal processing. After that, my group focused on improving the optical and electrical performance

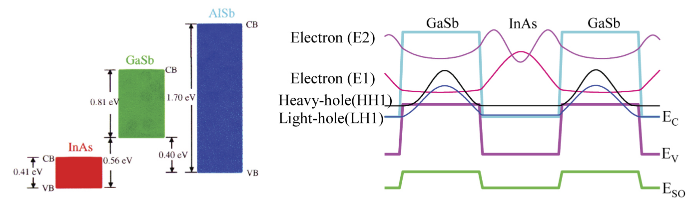

Figure 1. *(left) The band alignment of InAs, GaSb, and aluminum antimonide (AlSb) can be used to make an IR detector. (right) Wave functions of electrons and holes in an InAs/GaSb superlattice. CB: conduction band. VB: valence band. E_c: energy level of the conduction band. E_{so}: energy level of the spin-orbit band. E_v: energy level of the valence band.*

of the imager. We developed a new variant of a type-II superlattice, called M-structure, because of the M-shape of the band alignment (see Figure 2), which allows for more-flexible control of the energy gap, energy levels, and effective mass.[2] This novel material is incorporated at the main p-n junction of the detector to reduce the intensity of the electric field, thereby lowering the tunneling current through the junction, which reduces the noise at the detector level. In addition, significantly enhanced material quality provides high quantum efficiency—in excess of 50% and 75% in configurations for front-side and back-side illumination, respectively. We also minimize the surface leakage of the photodiode by using a double heterostructure architecture.[3] This design can be successfully passivated with various dielectric layers. Finally, we completely remove the substrate of the array to maximize the optical response in back-side illumination. This also reduces the effect of thermal stress when cooling the camera. Overall, our camera performs high-quality imaging, only limited by the performance of our testing set-up (see Figure 3). Temperature differences as low as 20mK can be detected within 100μs.[4]

The design and fabrication processes developed in this work make type-II superlattices a viable alternative to HgCdTe for IR imaging. In the future, the uniformity of this new material system and the lower cost of the substrate should significantly reduce the cost of focal-plane arrays. Moreover, the flexibility of

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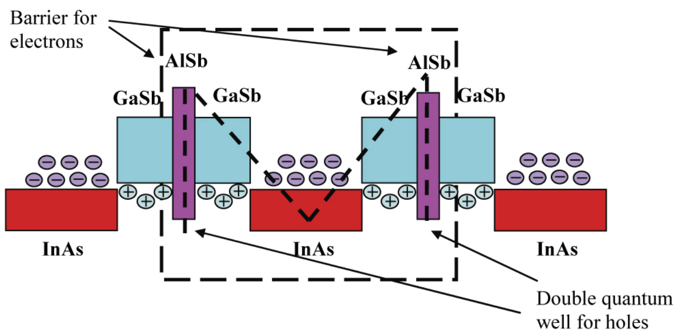

Figure 2. *The M-shape of this band alignment explains its name: M-structure. The inserted AlSb layers form barriers for electrons in the conduction band and a double quantum well for holes in the valence band.*

Figure 3. *(Left) Images taken with a 3–5μm IR camera based on type-II superlattices. (Right) Images from an 8–10μm camera.*

the superlattice is essential for the future development of multicolor imaging systems. In addition, developers can grow high-quality superlattices on alternative substrates because of the relatively small lattice mismatch of GaSb to GaAs and silicon. This collection of characteristics should encourage new applications of IR-photon detection.

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