10.1117/2.1201202.004122

Superlattice sees colder objects in two colors and high resolution

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A special class of semiconductor material can now detect two wavebands of light with energies less than a tenth of an electron volt in high resolution using the same IR camera.

The capabilities of IR sensing, commonly used for night vision, have been extended to see colder objects at high speed and potentially made cheaper by using a semiconductor material called the type II superlattice.[1] The beauty of this material is its relative ease in changing the detection wavelength in the IR, which has been experimentally demonstrated between 3 and 30μm.[2] To tune the detection wavelength in this 'broken-gap' superlattice, where the electrons and holes (negative and positive charge carriers, respectively) are spatially separated in alternating indium arsenide (InAs) and gallium antimonide (GaSb) quantum wells, one has only to change the layer thicknesses (and, consequently, the energy levels) to achieve an effective bandgap of interest. The wavelength tunability and material robustness of type III-V superlattice have generated much attention in recent years. This is especially true with respect to the performance of the material in narrow-energy-gap detectors, and specifically in a part of the electromagnetic spectrum between 8 and 12μm, called the long-wavelength IR (LWIR).

As the detection wavelength moves into the LWIR—where objects at and below room temperature emit most of their radiation—type II superlattice has several advantages. Because of the enormous combination of different InAs and GaSb thicknesses, as well as interface types that can be grown for any detection wavelength, the freedom to choose a favorable electronic band structure is a luxury that bulk materials lack. This ability has been used to optimize band alignment or for so-called Auger suppression.[3] Moreover, the material's flexibility lends itself to novel detector designs, an advantage that has been further expanded by incorporating aluminum antimonide (AlSb) into the superlattice, coined the M-barrier[4] by our group (see Figure 1). The M-barrier's ability to block unwanted current by tuning the band-edge energies has lowered dark current by an order of magnitude for LWIR detectors. The noise reduction

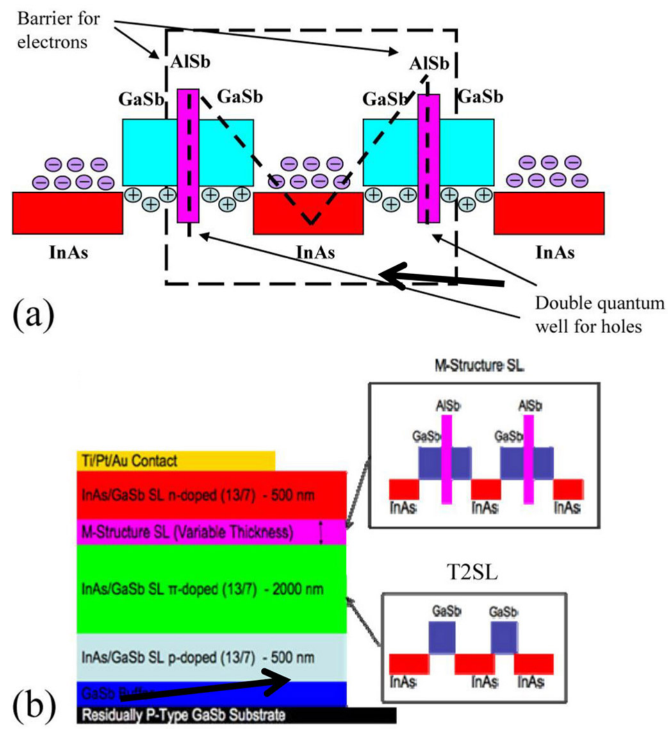

Figure 1. (a) The M-barrier's band alignment, incorporating aluminum antimonide (AlSb) into the type II indium arsenide/gallium antimonide (InAs/GaSb) superlattice (SL). (b) Novel detector design using the M-barrier within the long-wavelength IR detector structure. Ti: Titanium. Pt: Platinum. Au: Gold. n, p, and π refer to semiconductor types. T2SL: Type II superlattice.

offered by the M-barrier together with high optical efficiency enhances the detector's signal-to-noise ratio, which is instrumental for high-speed imaging. An additional advantage is excellent spectral uniformity, already shown in the LWIR,[5] which could potentially be translated to higher-yield, and higher-resolution imagers at lower production cost. The benefits of this technology have enabled us to push type II superlattice to its

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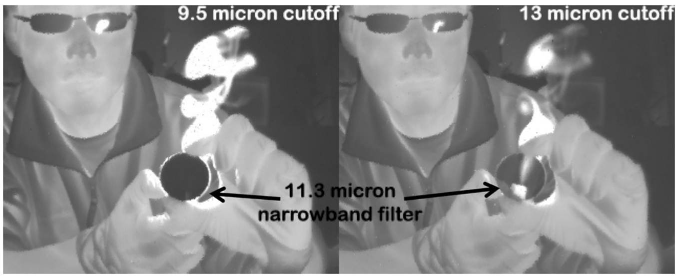

Figure 2. *Images of Center for Quantum Devices graduate student Edward Huang holding a lighter and a narrow-band filter centered at 11.3μm. The flame can be seen when imaged with the bandpass detectors sensitive up to 13μm (right), but not in the ones with shorter-detection wavelengths up to 9.5μm (left).*

logical next step: a camera capable of seeing distinct wavebands or colors in an all-in-one package, a feat not previously demonstrated by this material system in the LWIR.

The idea of capturing light simultaneously at different wavelengths is not new. Digital cameras in the visible spectrum are commonly equipped with detectors that sense red, green, and blue light to replicate the vast majority of colors perceived by the human eye. Multicolor detection in the IR spectrum, however, offers unique functionalities beyond color representation. The resonant frequencies of compounds can often be found in this spectral range, which means that chemical spectroscopy can be relayed in images in real time. When coupled with image-processing algorithms performed on multiple wavebands, the amount of information rendered in a particular scene is tremendous.

Our group engineered the detection energies on the cameras to be extremely narrow, with cutoff wavelengths at 9.5 and 13μm, in the range of roughly 0.1eV in energy. Realizing the camera was a difficult task because the light-absorbing layers are prone to surface leakage effects due to the size of the pixels, which are 30μm wide. We previously addressed this issue in an etching and passivation study.[6] In addition to this obstacle, we designed the detectors to be stacked one on top of the other, which provided spatially coincident pixel registration but added to the growth and fabrication challenges. We first reported a dual-band LWIR 320×256 pixel-sized type II superlattice in July 2011.[7] The imagery is shown in Figure 2, where graduate student Edward Huang holds an 11.3μm narrowband filter that appears transparent only in the 13μm channel.

More recently, we also demonstrated a large-format 640×512 pixel type II superlattice camera based on the same material design. The increased resolution is useful in applications such as long-range and high-altitude surveillance. The large-format camera requires only 0.5 milliseconds to capture a frame with temperature sensitivities as good as 0.015°C using F/2 optics. This demonstration is a significant step toward realizing high-performance, high-resolution, multifunctional, and low-cost type II superlattice cameras, making it an attractive IR sensing technology. In our future work, we intend to use the superlattice's wavelength tunability to realize multispectral cameras spanning the entire IR spectrum, beyond the LWIR region.

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