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Nanostructured Sensors

Type-II superlattices could be the next solution for fast and uniform infrared imaging.

By Manijeh Razeghi

Infrared photon imaging between 3 and 14 µm has important applications in security, defense, astronomy, and a number of other areas. Soldiers need infrared imaging to conduct surveillance in the dark. Astronomers and climatologists want imaging systems to learn more about our universe and world.

Researchers at the Center for Quantum Devices at Northwestern University have overcome several challenges in integrating Type II superlattice materials into IR imaging systems. Their innovative work using nanotechnology to create these structures has resulted in fabrication of the first high-quality IR camera with a 10 µm cutoff wavelength.

Limitations of IR Detectors

The two main categories of IR cameras, thermal detectors and photon detectors have recognized limitations.

Thermal detectors, such as bolometer arrays, offer a cheap solution for sensitive imaging at room temperature. However, due to their intrinsically slow thermal time constant, which is on the order of 10ms, they are not fast enough for critical applications where sensors need to be fast by themselves.

Photon detectors, on the other hand, are fast enough for many applications, but they need to be cooled to cryogenic temperatures, which is often impractical.

The leading technologies in IR photon detection are HgCdTe and Quantum Well Infrared Photodetectors (QWIPs). HgCdTe detectors offer uniform and sensitive imaging in the MWIR. However, when going toward longer wavelengths, the uniformity of the imager becomes more sensitive to the material composition. In addition, state of the art HgCdTe Focal Plane Arrays (FPAs) are grown on CdZnTe. This substrate is expensive and not commonly available. The high cost of lattice-matched substrates, combined with the low yield of the technology for wavelengths above 10 µm, makes HgCdTe-based cameras very expensive.

Photo taken with an MWIR camera based on Type-II superlattices.

QWIPs are very uniform but their optical response is low and they need to be cooled to lower temperatures (60K) to achieve performances similar to HgCdTe.

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These fundamental limitations stimulated our research for alternative technologies that would allow for fast, sensitive IR imaging.

Superlattice

Type-II InAs/GaSb superlattice, first proposed by Sai-Halasz et al. in the 1970s,[1]

As a result of this spatial separation, the effective bandgap of the superlattice may be lower than the bandgap of both InAs and GaSb.

Almost 30 years passed between the first introduction of this material and the fabrication of the first superlattice detectors because the growth of the superlattices require precise control of the thickness of the layers and atomically smooth interfaces.

Thanks to Molecular Beam Epitaxy (MBE) growth techniques, it is now possible to grow high quality material daily. By adjusting the thickness of the different layers, it is possible to tune the bandgap of the superlattice. Materials with cutoff wavelengths ranging from 3 to 30 µm have already been grown with good spatial uniformity using this technique.[2,3]

Thus, it is possible to select the optimum superlattice design depending on parameters other than the bandgap. Suppression of Auger recombination is one such example. When going toward longer cutoff wavelengths, the effective mass of electrons does not decrease as much as in HgCdTe, leading to potentially lower dark currents. In addition, more complex variations of the superlattice based on the introduction of ternary GaInSb or AlSb layers open new possibilities in terms of bandgap engineering.

Engineering Challenges

All these advantages made Type-II superlattice a very attractive material for infrared sensing and imaging. Several challenges had to be overcome before the first infrared cameras were fabricated from this material, however.

Most infrared imagers are made of two separate components that are bonded to each other with indium bumps. There is the array of sensors that will transform the photon radiation into an electronic signal, and there is the Read Out Integrated Circuit, which reads the current coming out from each individual pixel and transforms it in a video signal.

The quality of the FPA will mainly depend on two main parameters. First, the efficiency of the conversion process from photons to electrons—the quantum efficiency—needs to be as high as possible. Then, the dark current of the detectors should be as low as possible so that the noise of the detectors is low and the overall signal-to-noise ratio is high. Most of the efforts made in the past decade focused on improving these two parameters.

Nanostructure Design

The Center for Quantum Devices has made tremendous progress toward the fabrication of high quality imagers based on Type-II superlattice. Last year, researchers increased the number of superlattice periods in the absorbing region of their detectors and demonstrated quantum efficiencies as high as 75% similar to HgCdTe technology.[4]

The addition of an anti-reflective coating should bring the quantum efficiency above 90%. The Center for Quantum Devices also improved the electrical performances of detectors. Using a unique M-structure based on the introduction of AlSb layers inside the GaSb, it is possible to adjust the position of both the conduction and the valence bands.

This opens new possibilities in term of structure design. By introducing the proper M-structure inside a device, it is possible to reduce the electric field at the p-n junction. This leads to a one order of magnitude decrease of the dark current.[5]

Another issue related to this material is the surface leakage. As this is a low bandgap material, it is very sensitive to surface states. For many years, the passivation of this material has been a real scientific and technological issue. Recently, the introduction of a double heterostructure design with high bandgap contact regions significantly reduced the sensitivity of the material to surface effects.

These improvements and innovations have led to the fabrication of the first high-quality IR camera with a 10 µm cutoff wavelength[6]

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