The Grass is Always Blacker: Integration of Black GaSb with HOTBIRD FPAs

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Program: Topic Area

Project Objective:

High Operating Temperature Barrier Infrared Detectors (HOTBIRDs) are an emerging technology aimed at 2-15 μm wavelengths. They use alternating layers of semiconductor materials, called Type-II Superlattices. This allows engineering material properties such as bandgap. HOTBIRDs produced at JPL have shown operating temperatures of 150 K and have demonstrated lower 1/f noise than HgCdTe, presently the most common IR technology. HOTBIRDs are grown on GaSb wafers, and there is ~35% reflection loss for light passing through the vacuum-GaSb interface, lowering quantum efficiency (QE). While this can be mitigated with dielectric antireflection (AR) coatings, these are expensive and add significant risk of coating delamination. They also have limitations on bandwidth and angle of incidence.

In 2017, the authors conducted the R&TD Innovative Spontaneous Concept study “The Grass is Always Blacker: Antireflective GaSb by RIE Micromasking.” This proof-of-concept study demonstrated etching antireflective “grass” on GaSb using a Cl2 Reactive Ion Etch (RIE) with O2 micromasking (see **Fig. 1**). The grass-like micro-structure (see **Fig. 2**) is an effective graded-index material with demonstrated broadband antireflection (see **Fig. 3**) from 200 nm to 12.2 μm (nearly 6 octaves) and at up to 58° angle of incidence. For comparison, standard broadband dielectric antireflection coatings typically do not exceed 2 octaves of bandwidth or 45° angle of incidence. This 5-minute etch can be performed in-house, eliminating the need for expensive and risky dielectric coatings. This technology was reported as NTR 50673.

The ultimate aim of this project was to integrate GaSb grass with finished HOTBIRD focal plane arrays (FPAs). In FY2019, we aimed to a) demonstrate GaSb grass on single pixel MWIR HOTBIRD devices; b) develop a GaSb grass recipe using thermal test articles to mimic the thermal resistance of a full FPA stack; and c) fabricate MWIR detector arrays in preparation for demonstration of the technology on Focal Plane Arrays (FPAs) (in FY2020).

FY18/19 Results:

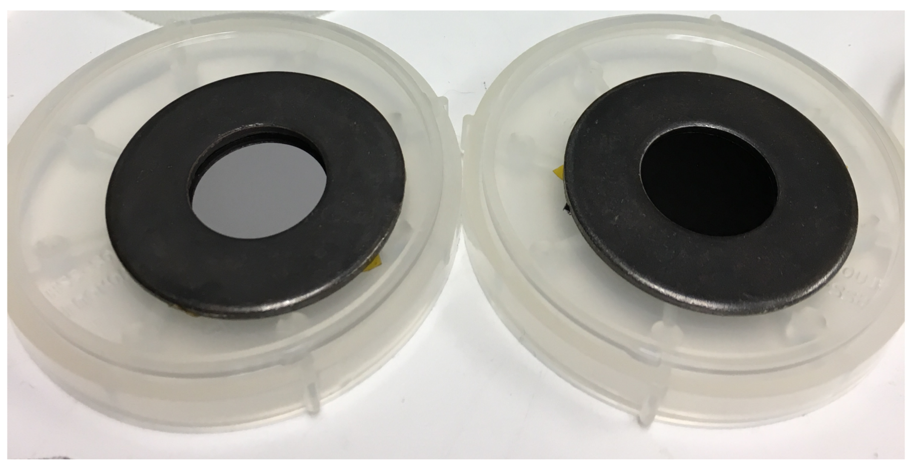

Fig. 1: Normal GaSb wafer and black GaSb wafer

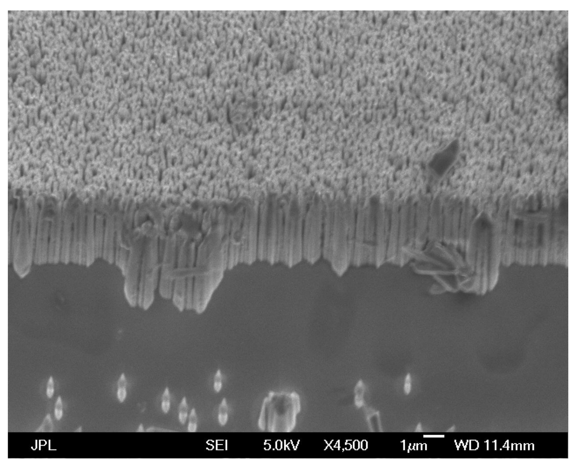

Fig. 2: SEM image of GaSb grass

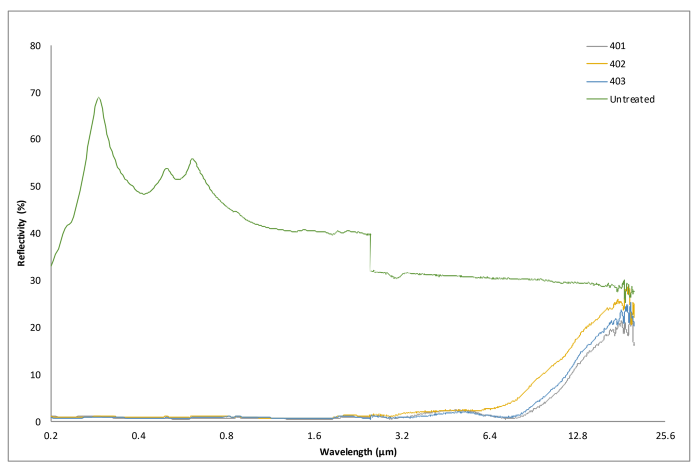

Fig. 3: Total reflectance vs. wavelength of GaSb grass

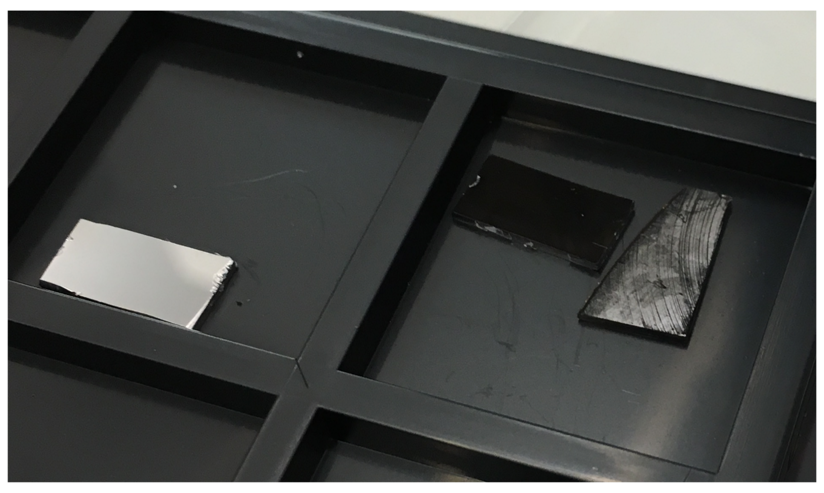

Fig. 4: Three single-pixel HOTBIRD devices, upside-down. Left to right: untreated, polished-then-etched, etched without polishing.

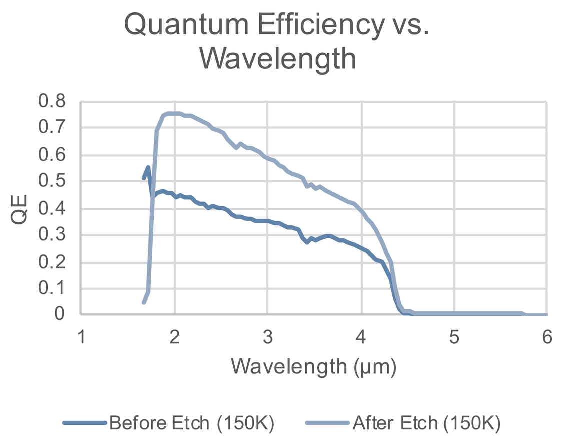

Fig. 5: Quantum efficiency vs. wavelength for single pixel bulk InAsSb device

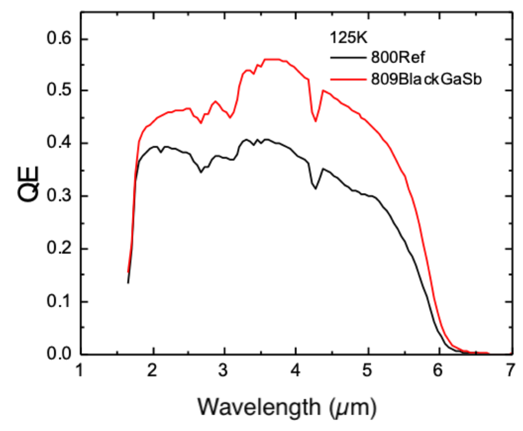

Fig. 6: Quantum efficiency vs. wavelength for single pixel HOTBIRD device

The overall technique is based on a micromasked etch first performed by an outside group at Purdue University [Lin et al., Nano Lett. 2015, 15, 8, 4993-5000]. This etch technique involves inductively coupled plasma (ICP) etching with Cl2 or BCl3 and a small amount of O2. The small amount of oxygen creates a micromasking effect, masking the etch in some places but allow it in others, causing the growth of nanopillars or “grass,” with widths of hundreds of nm and heights of several μm.

We sought to perform this technique on HOTBIRD infrared detectors. In FY2019 we reached the following milestones:

- Fabricated silicon-epoxy-GaSb thermal test articles for recipe development.
- Procured mid-wave infrared (MWIR) HOTBIRD wafers
- Fabricated MWIR HOTBIRD detector arrays
- Overcame uniformity problems in etch through development of a new polishing process (**Fig. 4**)
- Demonstrated GaSb grass on single pixel bulk InAsSb devices (showing antireflection up to 4.2 microns, **Fig. 5**)
- Demonstrated GaSb grass on single pixel MWIR HOTBIRD devices (showing antireflection up to 5.5 microns, **Fig. 6**)
- Made significant progress towards MWIR-cutoff antireflective grass on thermal test articles, but continued uniformity issues require more work.

In FY2020, these results will position us well to demonstrate MWIR-cutoff antireflective grass on a HOTBIRD FPA and to demonstrate LWIR antireflective grass on single-pixel HOTBIRD devices and on thermal test articles. This will lay the necessary groundwork for a future demonstration on LWIR HOTBIRD FPAs.

Benefits to NASA and JPL (or significance of results):

Improving the quantum efficiency of HOTBIRD detectors is important to a wide range of IR imaging and sounding projects at JPL. ***For instance, the CubeSat Infrared Atmospheric Sounder (CIRAS) employs HOTBIRD in the MWIR but does not employ an AR coating due to cost and risk.*** Techniques that reduce risk and cost and improve antireflective properties are greatly needed. Integrating black GaSb with HOTBIRDs will ***improve QE with broadband antireflection*** capable of high angles of incidence, ***at low cost and with no risk of delamination.*** This will make it ideal for CubeSat/SmallSat and other budget-limited earth and planetary science missions. The broadband antireflection and high angle-of-incidence will also make it ideal for spectrometer instruments. Furthermore, the technology would not be limited to HOTBIRDs; it would be transferable to any detector grown on GaSb.

IR sounders employing MWIR and LWIR HOTBIRDs will be proposed to future NASA Incubator or Explorer Earth Science Decadal Survey missions to address Planetary Boundary Layer and Atmospheric Motion Vector Winds. NOAA also has needs for CIRAS-like sounders to support operational forecasting and JPL. JPL will also be proposing the IR sounder technology based on CIRAS for planetary missions to provide accurate atmospheric temperature profile sounding of Mars. JPL is also proposing infrared instruments for the NASA Decadal Survey mission to address Surface Deformation/Change. ***JPL HOTBIRDs are applicable to a wide range of missions currently in place and proposed for the future. Integration with black GaSb could bring improved QE to smaller missions that cannot bear the cost and risk of a dielectric AR coating.***

Publications:

- Brian J. Pepper, Karl Y. Yee, Alexander Soibel, Anita M. Fisher, Sam A. Keo, Arezou Khoshakhlagh, and Sarath D. Gunapala "GaSb grass as a novel antireflective surface for infrared detectors", Proc. SPIE 11002, Infrared Technology and Applications XLV, 110020X (14 May 2019).

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