National Aeronautics and Space Administration

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

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Program: FY21 R&TD Topics **Strategic Focus Area: Remote/In Situ/Life Detection Sensors and Instruments**

Objectives

HOTBIRDs are an emerging infrared detector technology for 2-14 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. 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 risk coating delamination. They also have limitations on bandwidth and angle.

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. 1) is an effective graded-index material with demonstrated broadband antireflection (see Fig. 2) from 200 nm to 12.2 µm (nearly 6 octaves) and at up to 58° angle of incidence. 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).

Background

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). This problem is typically solved with dielectric antireflection coatings but these have many disadvantages.

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. The black GaSb metasurface, used in this project, has shown broadband antireflection (see Fig. 2) from 200 nm to 12.2 µm (nearly 6 octaves) and at up to 58° angle of incidence. 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.

Publications

[A] 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).

Approach and Results

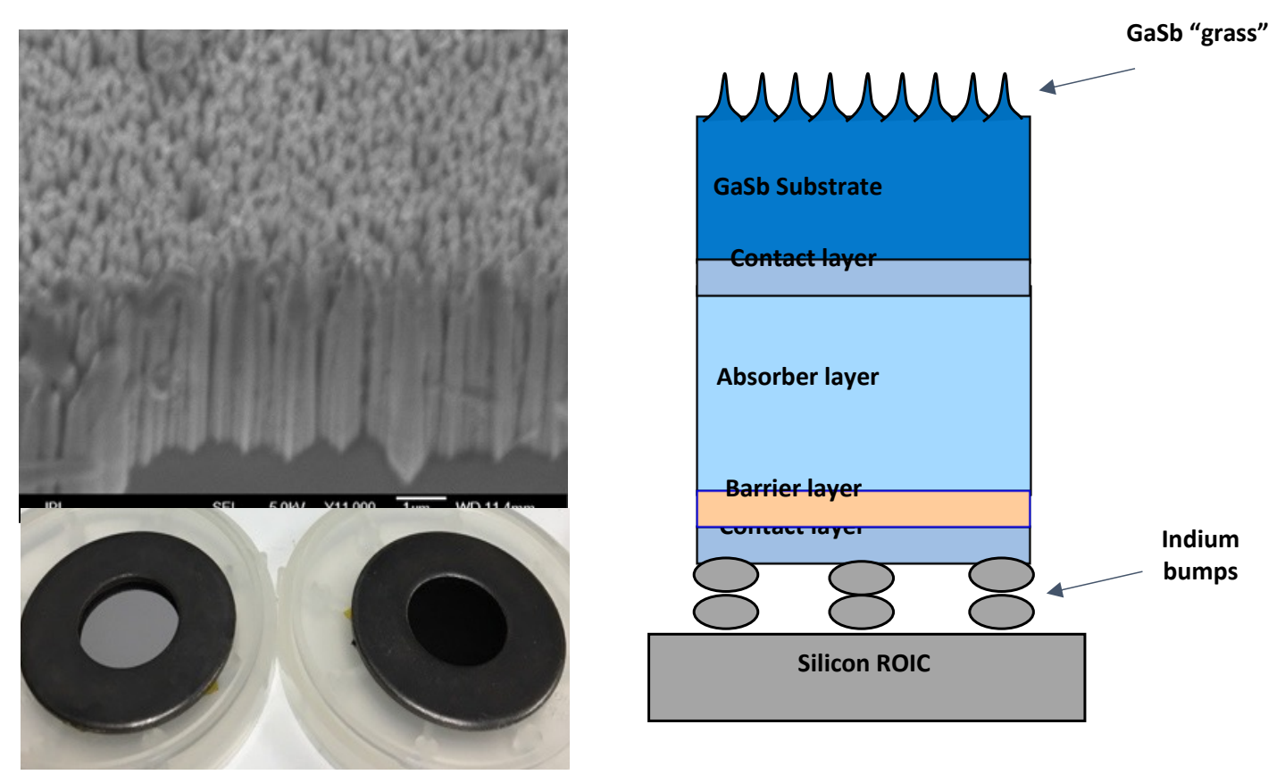

Fig 1: Top Left: SEM micrograph. Bottom Left: photo of black GaSb. Right: schematic diagram of FPA with black GaSb.

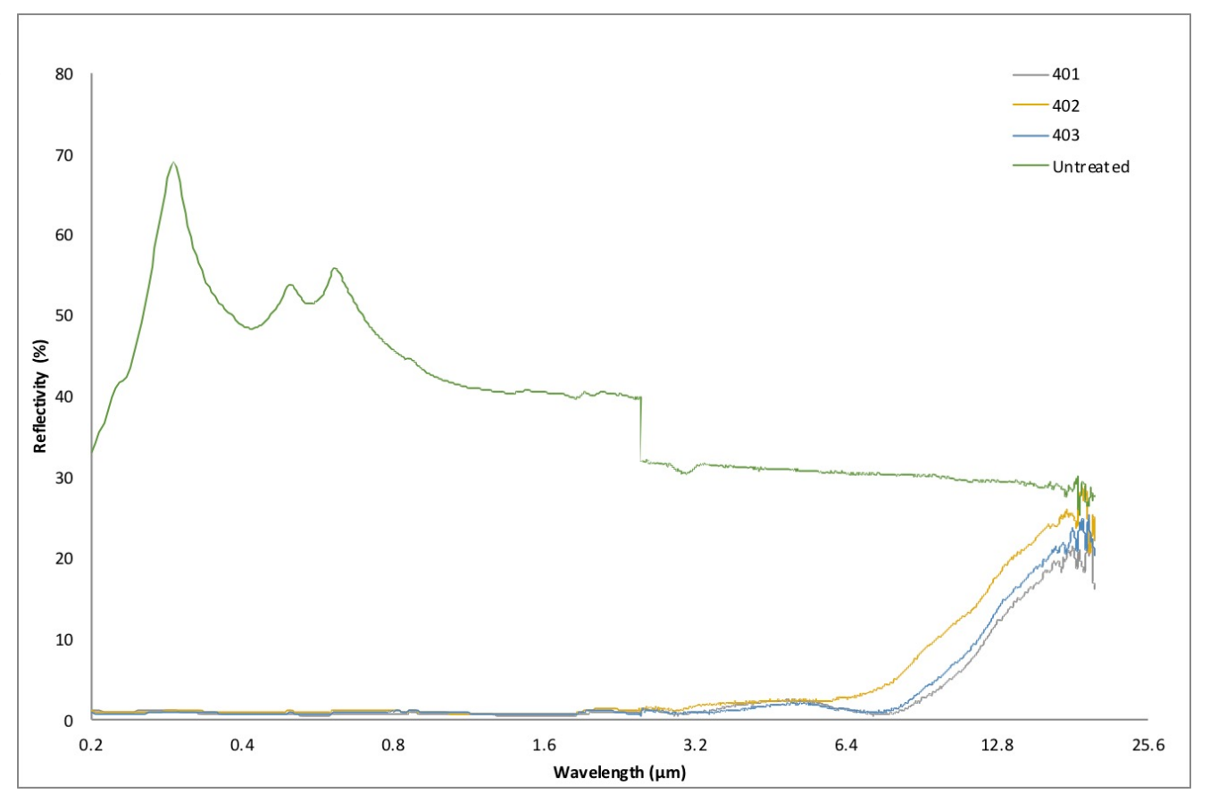

Fig 2: Total reflectivity vs. wavelength for GaSb and for etched GaSb grass.

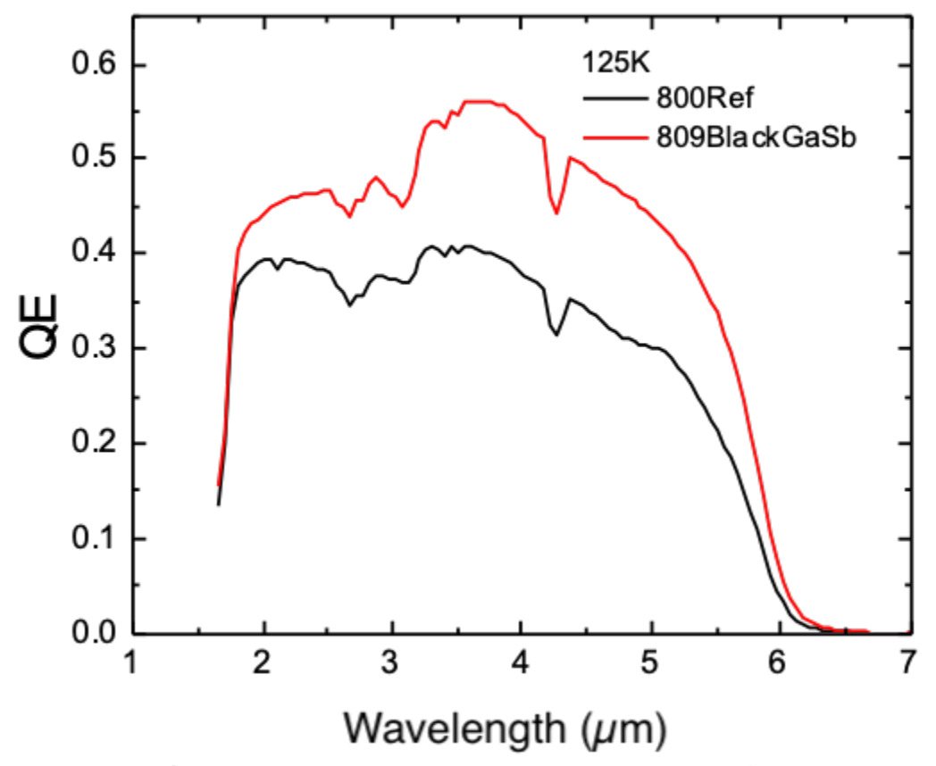

Fig 3: QE vs. wavelength of a MWIR HOTBIRD (black) and etched MWIR HOTBIRD (red), showing QE improvement.

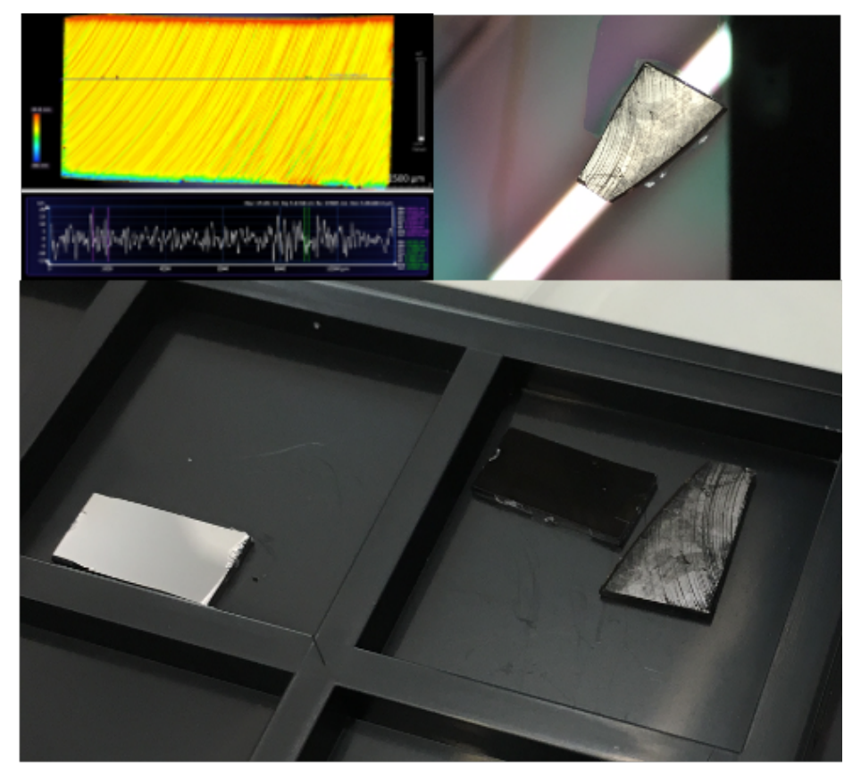

Fig 4: Top: nonuniformity due to DPT. Bottom: etching of polished and unpolished HOTBIRD samples

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.

In this original work, Lin et al., demonstrate antireflectivity from approximately 250 nm to 1900 nm. We subsequently improved the technique, with our work detailed in New Technology Report 50673. We adjusted etch parameters including ICP power, ICP bias, chamber pressure, temperature, and the flow rate of chlorine and oxygen used for the etch. We also experimented with different methods of achieving high thermal contact of the GaSb wafer to the carrier wafer, finding this to be a critical factor in obtaining good results. By optimizing all of these factors, we were able to obtain GaSb with drastically improved antireflective properties from that described in Lin et al.’s work. We demonstrated antireflectivity from 200 nm to 12.2 µm (nearly 6 octaves) and antirefectivity at angles of incidence as high as 58°.

HOTBIRD FPAs are composed of a silicon read out integrated circuit (ROIC) bonded to a detector array (DA) grown and patterned on a GaSb wafer. The gap between the two dies is then underfilled with epoxy for structural rigidity, and the GaSb wafer is then thinned by diamond point turning. In order to etch GaSb grass on the finished FPA, we will mount the FPA to a carrier wafer with wax or thermal paste and etch using the Cl2/O2 micromasking method pioneered in the earlier spontaneous R&TD.

Despite significant limitations in access to JPL imposed by the ongoing pandemic and Bobcat Fire in 2020, the project was ultimately able to achieve most of its stated milestones. The project fabricated MWIR HOTBIRD single pixel devices and focal plane arrays, demonstrated GaSb grass on single pixel MWIR HOTBIRD devices, meeting the targeted QE improvement equivalent to sub-10% reflection up to 5.5 microns. It was not possible to demonstrate the technology on LWIR single pixel devices as hoped; this task was not possible due to the many delays imposed by the COVID shutdown and associated safety protocols. This task also experienced uniformity problems (see Fig. 4). These problems arise because of the diamond point turning (DPT) used to thin the devices. This DPT process involves physically turning the wafer against a diamond tip, mechanically removing wafer material. It leaves a circular “tree ring” pattern, of several nm in height and several hundreds of microns in width. Even though this pattern is not visible to the naked eye, after etching the GaSb grass this pattern appears in the black surface, creating uniformity problems. Several polishing methods were evaluated, including isotropic etching, mechanical polishing, and chemical-mechanical planarization, but ultimately time ran out for this task.

Significance/Benefits to JPL and NASA

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.

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 for operational forecasting. 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 HOTBIRDs 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 dielectric coatings.

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Clearance Number:
RPC/JPL Task Number: R19130