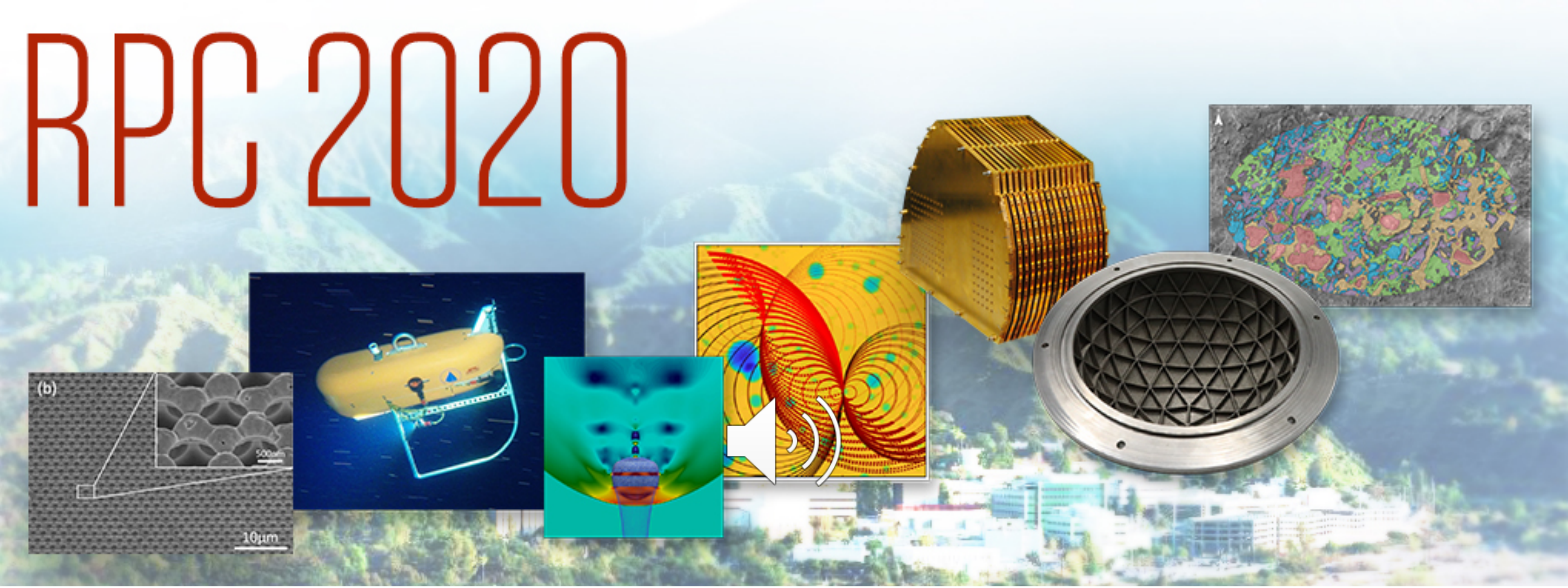

Virtual Research Presentation Conference

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

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Program: Topic
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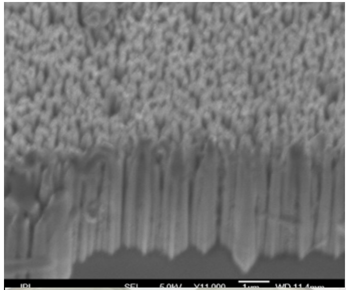
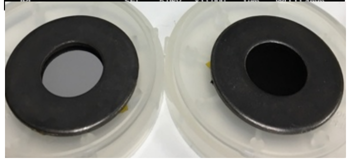
Tutorial Introduction

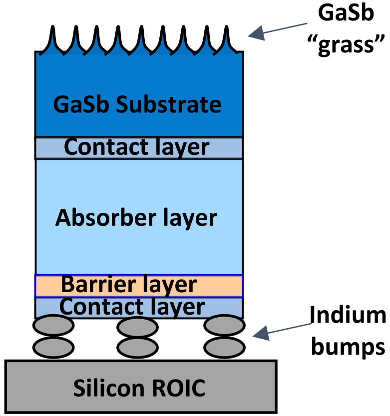
Abstract

In this task we worked on a novel broadband antireflective metasurface for infrared detectors called **black GaSb, or GaSb grass**. This black GaSb technology has been developed through the JPL R&TD program and has demonstrated antireflection from 200 nm to 12.2 μm (almost 6 octaves), and has shown commensurate increase in QE on MWIR HOTBIRD detectors. This metasurface does not require e-beam or other intensive fabrication but relies on inductively coupled plasma. This creates random micromasking due to surface roughness and plasma characteristics, resulting in a grassy surface that traps light. Also, as it's etched on the detector's GaSb material itself and not deposited, it can't delaminate.

Advantages over dielectric AR coatings: wider bandwidth (SWIR-VLWIR), higher angle of incidence, no risk of delamination and lower cost. We seek to extend this further into VLWIR, creating a true hyperspectral detector for the thermal infrared (TIR). Additionally, HOTBIRDs show cost, noise, uniformity, and temperature/SWaP advantages over HgCdTe. Together these cost/risk advantages could make this technology enabling for hyperspectral IR SmallSat constellations.







Problem Description

a) Context

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.

b) SOA (Comparison or advancement over current state-of-the-art)

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. 3) 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.

Problem Description *(cont.)*

c) Relevance to NASA and JPL (Impact on current or future programs)

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.***

Methodology

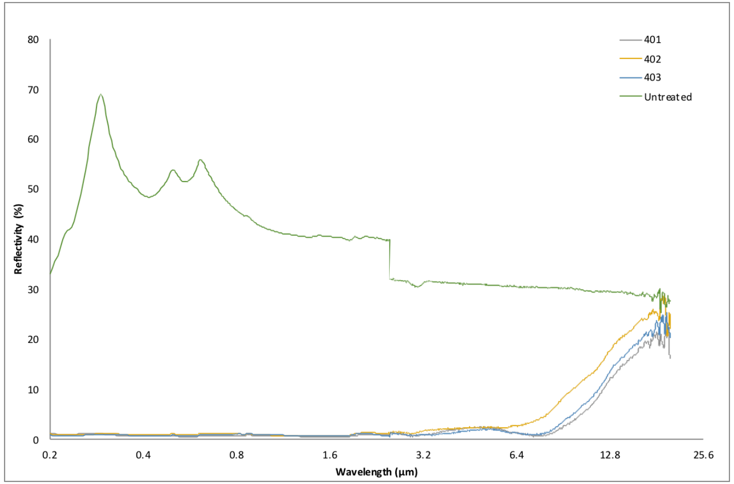
a) Formulation, theory or experiment description

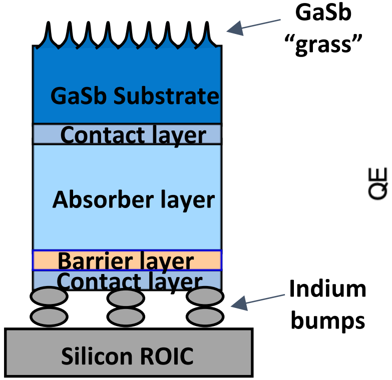
The overall technique is based on a micromasked etch first performed by an outside group at Purdue University [Lin et al., Nano Lett. 2015, 15, 8, 4993-5000]. This etch technique involves inductively coupled plasma (ICP) etching with Cl_2 or BCl_3 and a small amount of O_2. The small amount of oxygen 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. This group demonstrated antireflection in the near infrared (NIR), below 2 µm, but did not expand to cover short wave (SWIR), mid wave (MWIR), or long wave infrared (LWIR).

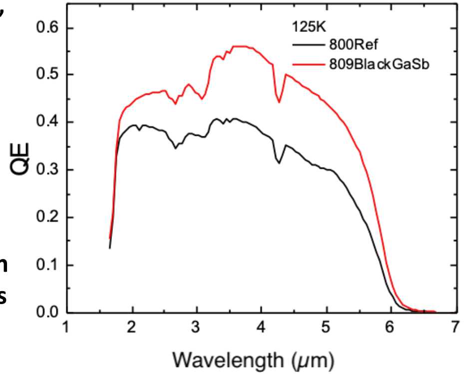
b) Innovation, advancement

Our innovation and advancement has been in two dimensions:

1. We have pushed the cutoff wavelength of the antireflection to cover 200 nm to 12.2 µm, covering NIR, SWIR, MWIR, and LWIR.
2. We have integrated the black GaSb with HOTBIRD detectors for broadband antireflection.







Results

a) Accomplishments versus goals

Complete:

- Grow (or procure externally) LWIR HOTBIRD wafers.
- Hybridize MWIR HOTBIRD FPAs using ISC0903 ROIC for demonstration of GaSb grass.

Partially complete:

- Demonstrate taller LWIR GaSb grass on single pixel LWIR HOTBIRD devices (QE improvement equivalent to sub-10% reflection up to 10 microns).

Incomplete:

- Demonstrate GaSb grass on MWIR HOTBIRD FPA (QE improvement equivalent to sub-10% reflection up to 5.5 microns).
- Demonstrate LWIR-cutoff antireflective GaSb grass on thermal test articles (sub-10% reflection up to 10 microns).

This topical R&TD was significantly impacted by JPL's COVID-19 shutdown. The project requires physical manipulation of semiconductor chips and was premised on having 52 weeks of access to JPL's Microdevices Laboratory (MDL). This was limited by COVID-19 and the recent Bobcat Fire; ultimately ***the project only had 24 weeks of unlimited access to the MDL and 5 weeks of heavily limited access.*** The project received a 6-month extension due to this.

b) Significance

These results position us well for a high scientific payoff in FY21. All of the “groundwork” milestones are complete: we have single pixel LWIR HOTBIRD devices prepared, and we have completely fabricated MWIR HOTBIRD focal plane arrays, including hybridization, underfill and thinning. Both sets of devices are ready to demonstrate black GaSb integration in the coming year. Achieving those objectives will demonstrate the viability of black GaSb as a broadband antireflective metasurface for real-life IR detectors.

Results *(cont.)*

c) Next steps

This project has received a 6-month extension due to the ongoing COVID-19 situation. We intend to make good use of that time to achieve the delayed milestones. In addition, this technology is the subject of a submitted ACT proposal under the current ROSES call. If funded, this proposal would cover advancing the technology to VLWIR for true broadband antireflection and hyperspectral instruments.

Publications and References

- 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).