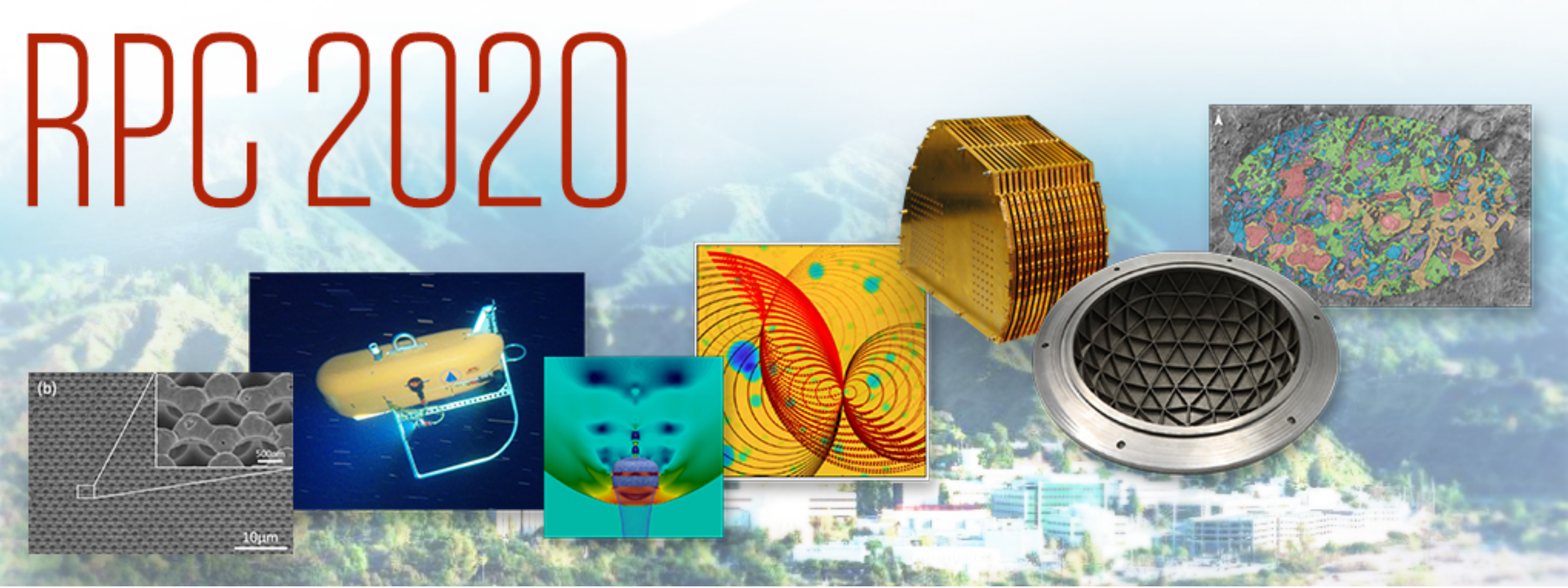

Virtual Research Presentation Conference

Integrated Semiconductor Laser Amplifier near 3 µm for OH Detection

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Program: Spontaneous Concept

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Jet Propulsion Laboratory
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Introduction

A high-power single-frequency laser at 2.9 µm based on a monolithically integrated semiconductor amplifier to a GaSb-based distributed feedback (DFB) laser has been designed to enable *in situ* measurements of the hydroxyl (OH) radical. OH is a crucial intermediate in the atmospheres of Earth and Mars, and play a key role in many other processes, including combustion and flame, chemistry of natural water systems, and biology. For example, OH is one of the most reactive species and plays a central role in the vertical profile of ozone, pollution chemistry (NOx and particulates), and controls global methane concentrations through oxidation. Measurements of OH rely on the availability of sensitive and selective methods for the probing and detection of OH.

Leveraging previous work on GaSb-based single-mode diode laser emitting near 2.9 µm, we designed an amplifier that uses the same active structure and can be monolithically integrated with a DFB laser.

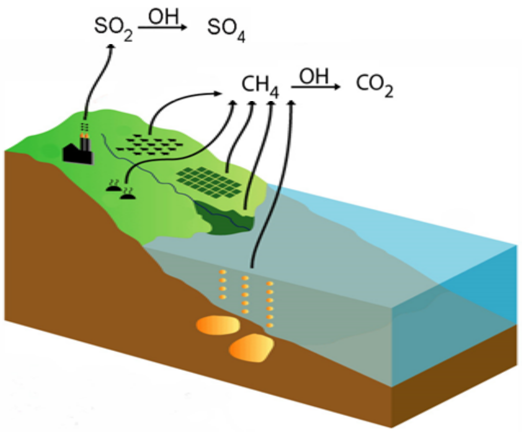
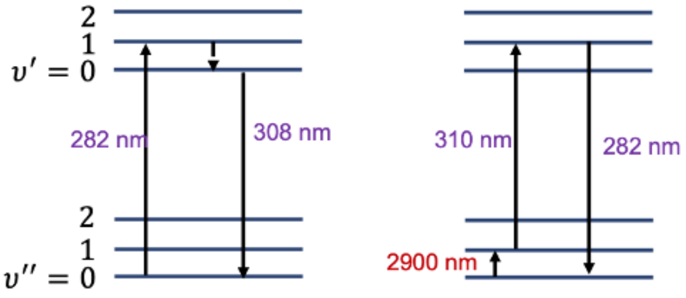


Illustration of OH reacting with CH_4 or SO_2 to form CO_2 or SO_4. Image credit: NASA GISS

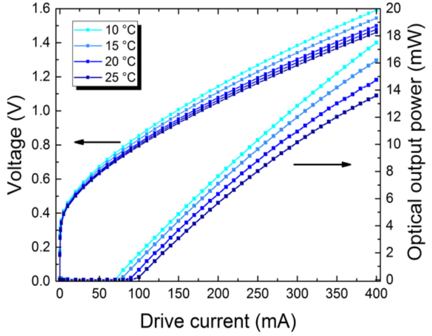
Problem Description

- Field measurements of OH use laser-induced fluorescence (LIF) systems, which require large, inefficient laser systems weighing more than 150 kg with high power consumption.
    - These systems use a 1-photon pumping scheme. This induces problems with scattered light that limit the sensitivity.
- Combining a high-power (~100 mW) single-mode semiconductor laser emitting near 2.9 μm with a single-frequency UV laser emitting near 310 nm, in a 2-wavelengths pumping scheme, will allow the development of a highly sensitive and compact LIF system by detecting OH fluorescence at 282 nm, avoiding noise due to background fluorescence.
    - The minimum detection concentration for a state-of-the-art 1-photon LIF systems for OH radicals is about 0.1 pptv for a 1-minute averaging period, while we anticipate an increased sensitivity by a factor 3-10 with this 2-photon background-free LIF method.
- Current state-of-the-art single-mode semiconductor lasers emit tens of mW of optical power at a wavelength of 2.9 μm.
    - Amplification is required to achieved 100 mW of single-frequency optical power.

Traditional LIF for OH measurement / **Proposed 2-wavelengths LIF for OH measurement**



Optical output power and voltage as a function of current (LIV) for a state-of-the-art GaSb-based DFB laser emitting at 2.9 μm



Benefits to NASA and JPL

- Developing a high-power single-frequency laser at 2.9 μm would enable an instrument that could revolutionized the current OH radical measurement techniques in the field, reducing weight, size, power draw as well as enhancing selectivity and sensitivity.

- Due to the size and power reduction compared to a 1-photon LIF system, this new instrument would target implementation on aircraft, balloons, and ultimately creating networks of miniature sensors that monitor trace species continuously.

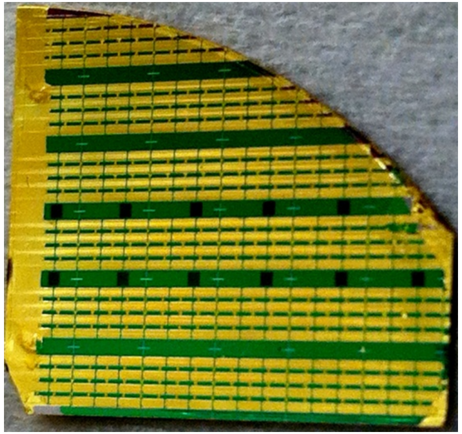
- Current remote sensing missions (e.g. NASA's OMI or ESA's TROPOMI) are not able to detect OH in the stratosphere/troposphere directly and therefore attempt to infer OH concentrations through detection of tracer species (e.g. formaldehyde).
  - These methods are difficult to test and validate on a global scale, as they rely on sparse OH measurements conducted in contrasting environments and seasons.
  - By developing technology that could be applied to a revolutionary global network of OH sensors, spaceborne observing architecture could be complemented and current remote sensing efforts to quantify OH on a global scale could be validated.

NASA Unmanned Science and Research Aircraft. Image credit: NASA Armstrong

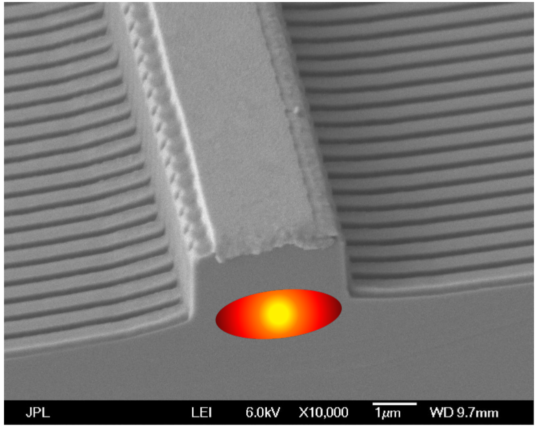
Methodology

- Developing a semiconductor-based laser amplifier would greatly reduce the size and required power consumption of a high-power single-frequency laser in the mid-infrared.
- Using a GaSb wafer with an active structure consisting of three 9 nm InGaAsSb type-I quantum wells (QW) separated by 30 nm quinary InGaAlAsSb barriers, with the QWs and barriers between two 2-µm-thick AlGaAsSb cladding layers that are p-doped (top layer) or n-doped (bottom layer), will enable optical emission near 2.9 µm.

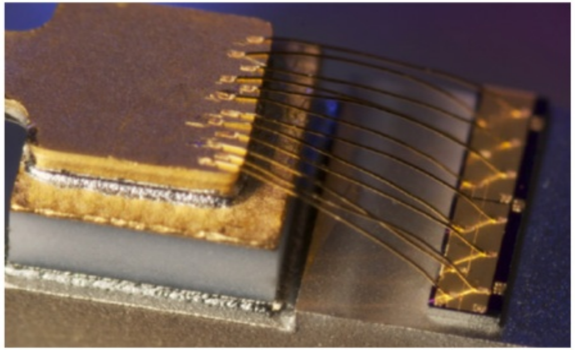
Processed GaSb wafer where several lasers have been fabricated



Scanning electron microscope (SEM) image of a single-mode DFB laser



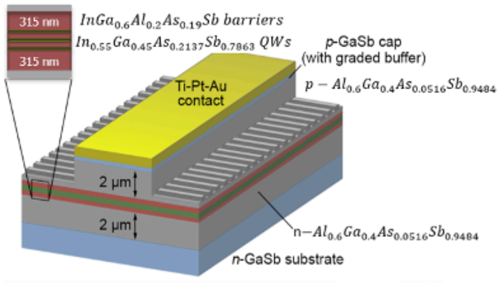
Picture of a 2-mm long DFB laser wire-bonded to a pad to facilitate electrical contact



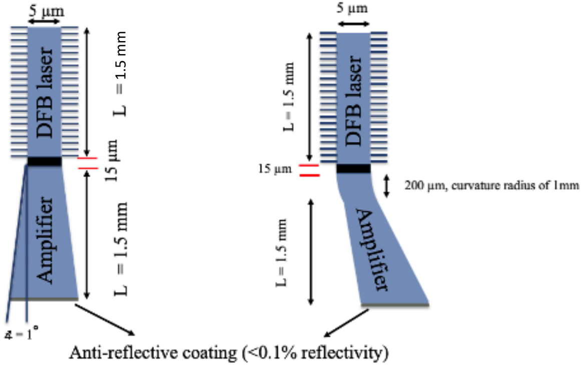
Integrated Amplifier Design

- Complete design of an amplifier to be integrated with a DFB laser on-a-chip

Schematic design of the GaSb-based DFB laser emitting at 2.9 µm. The grating's period is 836 nm.

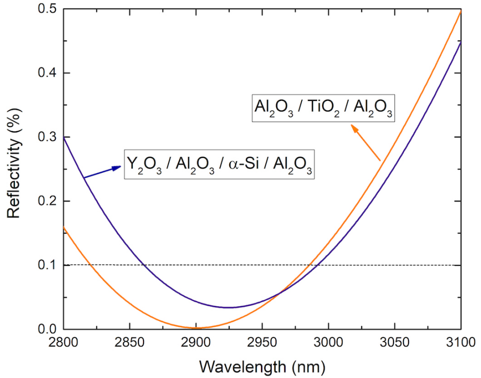


Two different amplifiers have been designed to achieve the targeted output optical power.



The DFB laser and amplifier are separated by a 15-µm long region to allow independent current pumping and avoid current leaking between regions.

Anti-reflective coatings with a reflectivity <0.1% have been designed to be deposited using electron-beam evaporation, blue curve, or atomic layer deposition (ALD), orange curve



We developed a novel deposition process for edge-facets coating that allows the use of an ALD system over the traditional electron-beam evaporation system.

- Every aspects of a monolithically integrated amplifier with a DFB laser have been designed for optical emission at 2.9 µm
- Fabrication of devices would show a complete proof of concept.

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