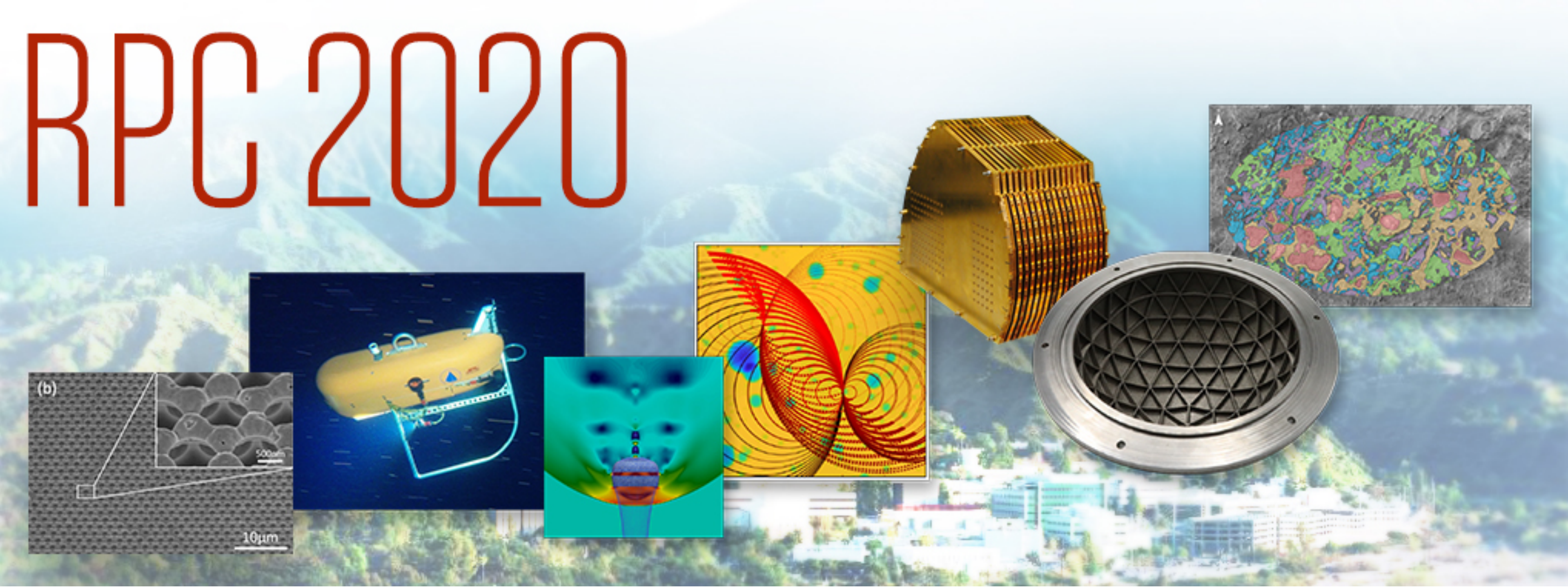


# Virtual Research Presentation Conference

## Development of Deep-Ultraviolet Solid-State Lasers for Raman Spectroscopy

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**Co-Is: Mohamed Sabry Mohamed (389), Peter Weigel (389)**
**Program: (Lew Allen, Strategic Initiative, Topic, Spontaneous Concept, or SURP)**

Assigned Presentation # R20101

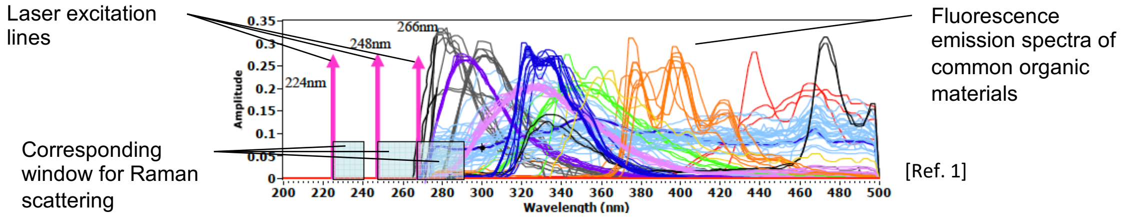
**Jet Propulsion Laboratory**
California Institute of Technology

# Tutorial Introduction


## Abstract

Spectroscopic analysis techniques such as Raman spectroscopy and luminescence measurements benefit immensely from the utilization of deep-ultraviolet coherent light sources. Deep-ultraviolet excitation provides multiple benefits which collectively contribute to an enhanced detection capability, for biosignatures and other species of interest. The current work aims to develop a solid-state platform for the generation of coherent deep-ultraviolet light. The technology concept relies on borate-based nonlinear optical crystal layers, which feature a broad transparency window and are capable of frequency upconversion into the deep-ultraviolet range. The implemented platform utilizes integrated photonic components to fulfill phase matching and additionally enhance the conversion efficiency of the device.


**Comparison of the Overlap of the Raman Emission Range with Material Fluorescence Under Different Excitation Wavelengths**



# Problem Description

a) Context

   a) Compact deep-ultraviolet (deep-UV) coherent light sources are required for spectroscopic analysis on planetary exploration missions

   b) State-of-the-art technology for coherent deep-UV sources faces technical hurdles, resulting in devices with limited performance and reliability

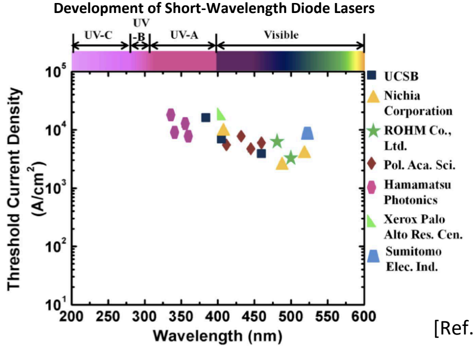
b) Comparison with State-of-the-Art

| Criterion | State-of-the-Art NeCu Gas Laser | Proposed Solid-State Laser |
|---|---|---|
| **Mass** | 470 g | ~100 g |
| **Power Output** | ~40 µs of <20 µW @80 Hz, pulsed | >1 mW, continuous-wave |
| **Volume/Size** | ~500 $cm^3$/ ~5 cm diameter, 25 cm length | <250 $cm^3$/ ~1 $cm^2$ chip area |
| **Emission Wavelength** | 248.6 ± 0.05 nm (fixed) | Any wavelength down to 225 nm |
| **Beam Quality ($M^2$)** | >30 | ≈1.1 (near diffraction limit) |
| **Robustness** | Gas tube | Solid-state components |
| **Spot Size** | ~100 microns | <3 microns |

c) Relevance to NASA and JPL

   a) Raman spectroscopy and luminescence spectroscopy instruments are essential tools for life detection and assessment of habitability

   b) The developed technology will contribute to planetary instruments carried on upcoming exploratory missions, which will require reliable and robust devices

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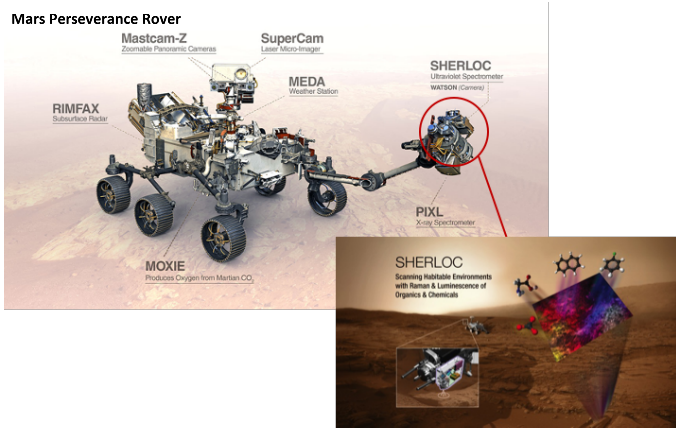
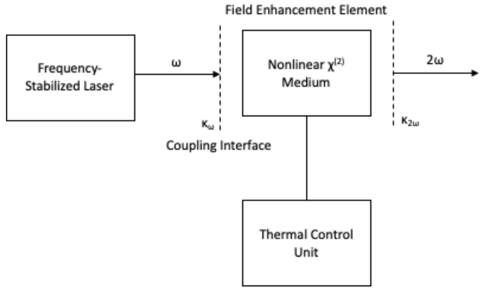


# Methodology

a) Formulation

- a) Raman spectroscopy and other spectroscopic techniques benefit greatly from deep-UV sources
- b) Deep-UV generation can be generated in nonlinear media with short-wavelength transparency combined with suitable dispersion properties
- c) Cladded optical-grade β-barium borate (β-BBO) layers enable the fabrication of integrated photonic elements
- d) Phase-matching in nonlinear waveguides is required for efficient nonlinear frequency conversion

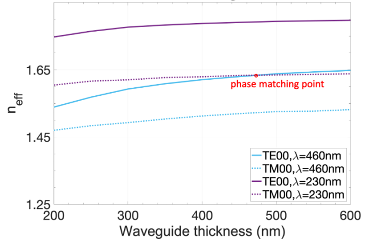
Deep-UV Generation Scheme



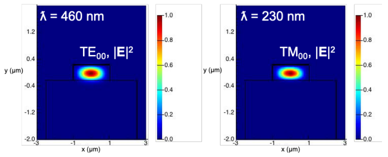

b) Innovation / Advancement

- a) A novel thin-layer β-BBO-on-insulator platform supports nonlinear optical processes spanning the near-infrared to deep-ultraviolet range
- b) Phase matching can be precisely engineered using integrated photonic elements
- c) Compact, high-power semiconductor light sources can be incorporated as optical pumps

Effective Index vs. Waveguide Thickness




β-BBO Waveguide Modal Field Profiles



# Results

a) Goals and accomplishments

- a) Development of designs for nonlinear frequency conversion

  ➔ Phase-matched β-BBO nonlinear waveguides designed

- b) Demonstration of patterning in free-standing β-BBO crystal

  ➔ High-aspect ratio (> 5:1) patterning of β-BBO crystal demonstrated using focused-ion-beam milling

  ➔ Anhydrous electron-beam lithographic patterning of β-BBO implemented and is in the optimization phase

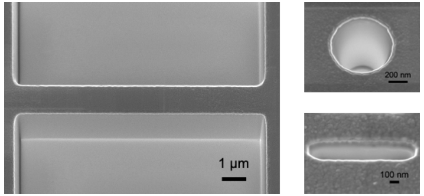
- c) Thin-layer development for β-BBO

  ➔ Initial implementation of thin β-BBO layers (5 µm-thickness) using optical-grade polymer cladding, currently being transitioned to silica cladding

- d) Implementation of a measurement testbed

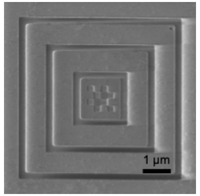
  ➔ Measurement setup has been implemented for the characterization of visible-to-deep-UV integrated photonic chips

**Focused-Ion-Beam Patterning**



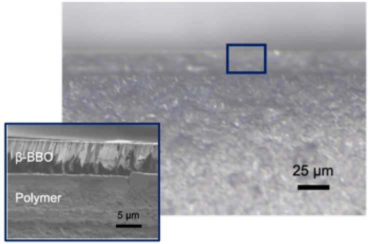

Micro/nanoscale features directly milled in free-standing β-BBO crystals.

**Electron-Beam Lithography**




Patterned chromium hard mask on β-BBO free-standing crystal through anhydrous processing.

**Thin-Layer β-BBO**



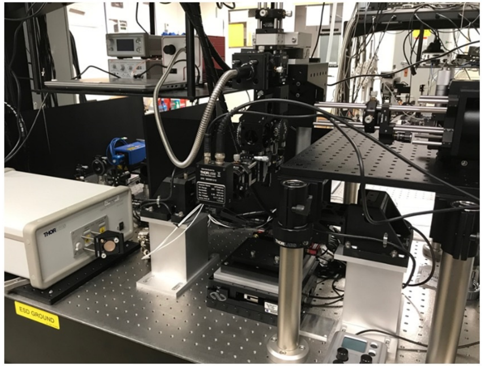

Cross-sectional brightfield microscopy image of thin layer β-BBO, and the corresponding scanning electron microscopy close-up in the inset. The cross-sectional cut was prepared by dicing.

# Results

a) Significance
   a) Existing nonlinear optical layers do not operate in the short-visible to deep-UV wavelength range
   b) A mature micro-/nano-scale fabrication process for β-BBO has not been developed yet
   c) This technology development is unique and complements the UV detection competency at the Microdevices Laboratory

b) Next steps
   a) Optimization of the fabrication process
   b) Fabricating and testing the designed photonic chips to target propagation losses below 5 $dBcm^{-1}$ in β-BBO waveguides at the pump wavelength

**Measurement Testbed at the Microdevices Laboratory**



# Publications and References

Publications:

New Technology Report # 51684, “Method for the Preparation of Thin-Layer Beta-Barium Borate”

References:

[1] W. F. Hug et al., Chemical and Biological Sensors for Industrial and Environmental Monitoring II 6378, 63780S (2006).

[2] S. Zhao and Z. Mi, IEEE J. Quantum Electron. 54, 1-9 (2018).

# Acknowledgements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