National Aeronautics and Space Administration

Deep-ultraviolet solid-state lasers for Raman spectroscopy

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

Objectives

Primary Objective: To develop a solid-state deep-UV coherent light source based on second harmonic generation in a nonlinear crystal, operating in continuous-wave mode and exhibiting near diffraction-limited beam quality, for the purpose of *in situ* organics detection via Raman spectroscopy.

Why Now: Recent development of nitride-based, high-power semiconductor lasers in the blue wavelength region.

Background

Detecting the trace quantities of organic molecules with minimal sample handle of *in situ* platforms is needed for a wide variety of mission that NASA plans to fly in the coming decades. This research delved into the development of a UV laser source capable of performing that *in situ* detection. This research team chose to develop a nonlinear photonic integrated circuit built on beta-barium borate (BBO), a material well known for its visible-to-UV nonlinear capabilities in bulk crystals. By developing an integrated BBO platform, the nonlinear process is much more efficient, controllable, and compact.

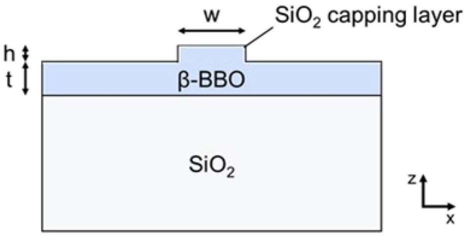

Fig. 1: Cross-section of the photonic device.

Approach and Results

Approach: Design and fabricate thin-film beta-barium borate (BBO) photonic integrated circuits.

Results

1. Design efficient nonlinear photonic devices (achieved July 2020).
2. Build nonlinear UV generation lab setup for device testing (achieved June 2021).
3. Develop and demonstrate < 200 nm BBO feature sizes (achieved July 2021).
4. Thin BBO crystal samples to < 2 um (achieved August 2021).

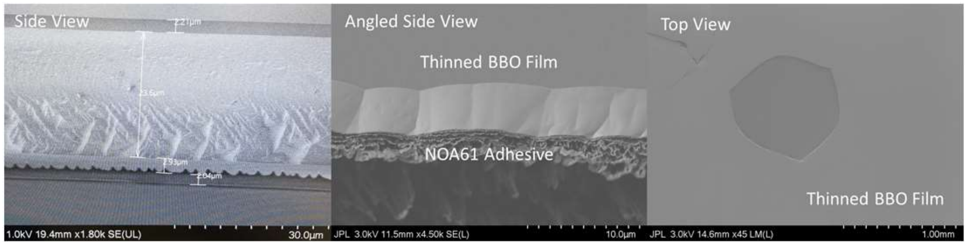

Fig. 2: Left: Side view of a cleaved BBO film on NOA 61. Middle: Angled view of a thinned BBO film. Right: Top view of a defect in thin BBO caused during processing.

Significance/Benefits to JPL and NASA

This work represents a significant step towards realizing chip-scale UV lasers for deep-space in situ detection of organic compounds. In particular, this is the first demonstration of thin-film beta-barium borate (BBO)-on-insulator waveguides. The design and fabrication challenges overcome over the course of this funded effort include consistent fabrication of BBO devices (uniquely challenging due to the fact that BBO is hygroscopic), realization of BBO-on-insulator, and simulation/design capabilities for blue, UV, and blue-to-UV nonlinear waveguides.

While the ultimate goal of nonlinear generation of UV light was unfortunately not achieved due to limited access to JPL's facilities during the course of the work period, the accomplishments achieved here demonstrate that it is indeed possible to create thin film BBO-on-insulator dies and devices. This was arguably the largest hurdle to overcome on the path towards a chip-scale UV source. Given that a nonlinear UV testbed has been built at the Microdevices Laboratory as part of this effort, there are few challenges remaining to realize a nonlinear visible-to-UV device on the thin film BBO-on-insulator platform..

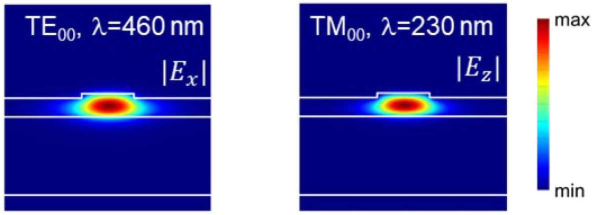

Fig. 3: Left: Simulated TE_{00} mode at the fundamental harmonic wavelength, 460 nm.
Right: Simulated phase-matched TM_{00} mode at the second harmonic wavelength, 230 nm.

Publications

[A] M. S. Mohamed and S. Forouhar, “Chip-Scale Beta-Barium Borate Platform for Near-Infrared to Deep-Ultraviolet Nonlinear Integrated Photonics,” in *2021 Conference on Lasers and Electro-Optics/Europe and European Quantum Electronics*, OSA Technical Digest (Optical Society of America, Washington, D.C., 2021), paper cd_p_9.

[B] M. S. Mohamed and S. Forouhar, “Beta-Barium Borate-on-Insulator Waveguide Design for Coherent Deep-Ultraviolet Light Generation,” in *26th Microoptics Conference (MOC2021)*, Japan Soc. Appl. Phys.

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