**Component:** NAVY  
**Topic #:** N201-058  
**Title:** Affordable and Efficient High-Power Long Wavelength Infrared Quantum Cascade Lasers  
**Technology Areas:** Sensors  
**Acquisition Program:** PEO IWS 2: Surface Electronic Warfare Improvement Program (SEWIP) Block 4

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**OBJECTIVE:** Develop and demonstrate an affordable, high-power, highly efficient, quantum cascade laser technology for operation in the long wavelength infrared spectrum.

**DESCRIPTION:** Solid-state laser systems have a wealth of military applications, including target designators, illuminators, secure communications, countermeasures, and directed energy weapons. Providing effectiveness in diverse environments and flexibility in the face of rapidly changing operational demands, and addressing the range of enemy threats require lasers operating across wide parts of the electro-optic/infrared (EO/IR) spectra. As with all military systems, issues of efficiency, size, weight, and power (SWaP) and especially cost, are paramount concerns. No single laser system can address all operational requirements, and no single laser technology can operate equally well across the wide span of the visible and infrared bands.

To date, a great deal of effort has been invested in developing compact, affordable, and efficient laser diode technology in the visible, short-wave infrared (SWIR), and mid-wave infrared (MWIR) bands, especially in the area of quantum cascade lasers (QCLs) for the MWIR. QCL-based laser modules have been demonstrated in these bands. They are compact (approximately a few hundred cubic centimeters), lightweight (less than a kilogram), and flexible in application. Alternate laser technologies of comparable performance would necessitate at least an order of magnitude increase in size and weight. The long-wave infrared (LWIR) band, especially the atmospheric transmission window of 8-10.5 microns (µm), has received less attention. This is not to suggest that the LWIR band is less important. Indeed, the LWIR band possesses characteristics that make it particularly attractive for many application – but progress in the area is slowed by the difficulty of fabricating suitable device structures.

Recent QCL research in the 9-11 µm wavelength band has demonstrated single device continuous wave (CW) output powers of 2-3 W with corresponding "wall plug" efficiencies (WPE) of around 12% (WPE is defined as the ratio of total optical output power to the input electrical power). Commercially available devices (what few exist) produce far less power (typically less than 1 W), exhibit efficiencies (WPE) around 5%, and cost in excess of $5000 in small quantities. Granted, wide scale application of LWIR QCLs in Navy systems would create the demand necessary to somewhat reduce device cost. However, before this can happen, a viable technical path must be shown toward achieving both the required performance and reliable, repeatable manufacture. A per-device cost reduction of at least one order of magnitude is needed.

The Navy needs a high-power, high-efficiency, and affordable LWIR QCL technology. Specifically, a QCL technology that operates over the wavelengths 8-10.5 µm is required. For a single device (a single QCL emitter, not an optically combined array of emitters), the goals for optical output power and WPE are 4 W and 16%, respectively, at room temperature. These power and efficiency goals are understood to apply over the entire 8-10.5 µm band. That is, a single QCL technology is desired such that the entire band of interest can be covered by the same basic device design through parametric design changes (e.g., emitter length, optical waveguide width). Approaches that use different device structures to cover separate parts of the band are not of interest. Prototype devices produced under this effort need not cover the entire band of interest (or even substantial portions of it). However, prototype devices should be
demonstrated at representative wavelengths sufficient to show applicability of the technology across the full band of interest. As the combining of output from multiple devices is envisioned for some applications, the output beam should be CW and nearly diffraction limited with M2 of 2.0 or less.

Fundamental to this effort is development of a path toward affordable manufacture of the proposed QCL technology. Therefore, this effort should not only deliver prototype devices, but should also establish and mature the essential fabrication process such that (upon validation of the process) the devices can be reliably manufactured with high batch-to-batch repeatability and yield. Full validation of a semiconductor fabrication process is beyond the scope of Phase I and II of this effort and is left to Phase III. As device design and process development typically require an iterative and incremental approach, it is expected that multiple prototype devices will be fabricated and tested during this effort. Therefore, at least two individual devices shall be tested and delivered to the Naval Research Laboratory.

PHASE I: Propose a concept for an affordable, efficient, and high-power QCL technology as described above. Demonstrate the feasibility of the proposed approach and predict the ability of the concept to achieve the required parameters in the Description. Demonstrate feasibility by some combination of analysis, modelling, and simulation. Address affordability initially by identification of the key manufacturing steps and processes anticipated for manufacture of the device in Phase II, their maturity and availability in the industry, and their projected cost. The Phase I Option, if exercised, will include a device specification, initial process description, and test plan in preparation for device prototype development and demonstration in Phase II.

PHASE II: Develop and demonstrate a prototype QCL technology as detailed in the Description. Demonstrate that the technology (including the nascent manufacturing process) meets the requirements in the Description. Demonstrate the technology in two progressive parts: a demonstration that a prototype QCL meets the power and WPE requirements in the Description; and a demonstration that multiple (at least four) prototype (packaged and ready to use) CW QCLs meet the performance requirements of the Description such that manufacturing repeatability and the ability of the devices to operate at more than one wavelength within the LWIR band is shown. After electrical performance testing, deliver the prototype devices to the Naval Research Laboratory. Make available the prototype manufacturing process, as documented by initial process control specifications, process definitions, calibration instructions, in-process quality protocols, etc., for review by Naval Research Laboratory personnel or their authorized representatives. Deliver an analysis of production cost based on the resulting manufacturing process and an assessment of the MRL achieved at the end of the effort.

PHASE III DUAL-USE APPLICATIONS: Support the Navy in transitioning the technology for Government use and Low Rate Initial Production (LRIP). Assist in applying the design to (and maturing the process for) specific QCL devices (specific wavelength devices, packaging, etc.) since the prototype devices and initial manufacturing process resulting from Phase II are a generic demonstration of the technology. Mature and validate the prototype manufacturing process developed in Phase II for production at qualified foundries.

The technology resulting from this effort will have application in the fields of laser spectroscopy and communications.

REFERENCES:


KEYWORDS: Solid-State Laser; Quantum Cascade Laser; QCL; Long Wave Infrared; LWIR; Semiconductor Fabrication; Laser Diode; Laser Systems