# Physical Sciences

## Quantum-Dot Laser for Wavelengths of 1.8 to 2.3 μm

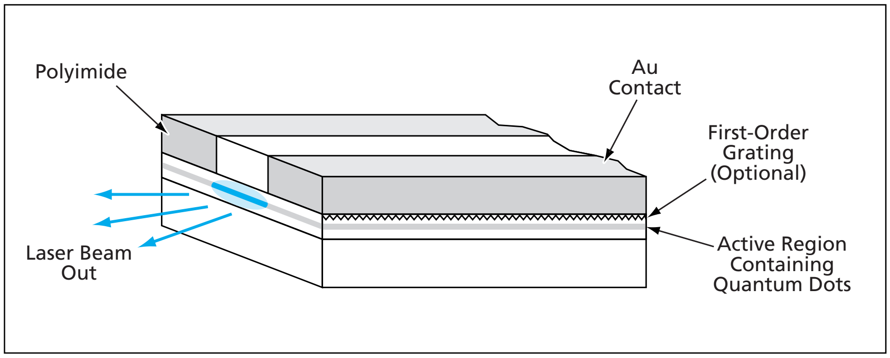
**Process conditions must be controlled to form quantum dots at sufficient density.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The figure depicts a proposed semiconductor laser, based on In(As)Sb quantum dots on a (001) InP substrate, that would operate in the wavelength range between 1.8 and 2.3 μm. InSb and InAsSb are the smallest-bandgap conventional III-V semiconductor materials, and the present proposal is an attempt to exploit the small bandgaps by using InSb and InAsSb nanostructures as mid-infrared emitters.

The most closely related prior III-V semiconductor lasers are based, variously, on strained InGaAs quantum wells and InAs quantum dots on InP substrates. The emission wavelengths of these prior devices are limited to about 2.1 μm because of critical quantum-well thickness limitations for these lattice-mismatched material systems.

The major obstacle to realizing the proposed laser is the difficulty of fabricating InSb quantum dots in sufficient density on an InP substrate. This difficulty arises partly because of the weakness of the bond between In and Sb and partly because of the high temperature needed to crack metalorganic precursor compounds during the vapor-phase epitaxy used to grow quantum dots: The mobility of the weakly bound In at the high growth temperature is so high that In adatoms migrate easily on the growth surface, resulting in the formation of large InSb islands at a density, usually less than $5 \times 10^9$ cm$^{-2}$, that is too low for laser operation.




In the **Proposed Semiconductor Laser**, the active region would contain In(As)Sb quantum dots, which emit at wavelengths from 1.7 to 2.3 μm. The first-order grating would be included, optionally, to select operation at a single wavelength.

The mobility of the In adatoms could be reduced by introducing As atoms to the growth surface because the In-As bond is about 30 percent stronger than is the In-Sb bond. The fabrication of the proposed laser would include a recently demonstrated process that involves the use of alternative supplies of precursors to separate group-III and group-V species to establish local non-equilibrium process conditions, so that In(As)Sb quantum dots assemble themselves on a (001) InP substrate at a density as high as $4 \times 10^{10}$ cm$^{-2}$. Room-temperature photoluminescence spectra of quantum dots formed by this process indicate that they emit at wavelengths from 1.7 to 2.3 μm.

*This work was done by Yueming Qiu of Caltech for* **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

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## Tunable Filter Made From Three Coupled WGM Resonators

**This is a prototype of high-performance filters for photonic applications.**

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A tunable third-order band-pass optical filter has been constructed as an assembly of three coupled, tunable, whispering-gallery-mode resonators similar to the one described in "Whispering-Gallery-Mode Tunable Narrow-Band-Pass Filter" (NPO-30896), *NASA Tech Briefs*, Vol. 28, No. 4 (April 2004), page 5a. This filter offers a combination of four characteristics that are desirable for potential applications in photonics: (1) wide real-time tunability accompanied by a high-order filter function, (2) narrowness of the passband, (3) relatively low loss between input and output coupling optical fibers, and (4) a sparse spectrum. In contrast, prior tunable band-pass optical filters have exhibited, at most, two of these four characteristics.

As described in several prior *NASA Tech Briefs* articles, a whispering-gallery-mode (WGM) resonator is a spheroidal, disklike, or toroidal body made of a highly transparent material. It is so named because it is designed to exploit whispering-gallery electromagnetic modes, which are waveguide modes that propagate circumferentially and are concentrated in a narrow toroidal region centered on the equatorial plane and located near the outermost edge.

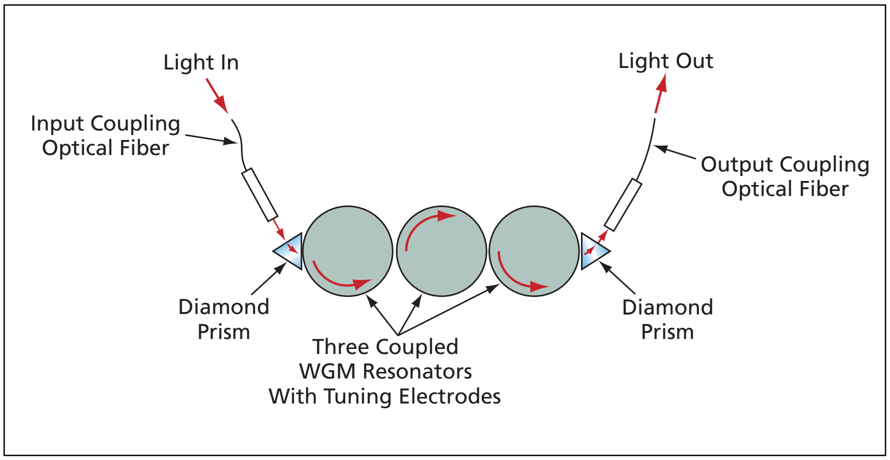


Figure 1. **Three Coupled, Tunable WGM Resonators** constitute a third-order tunable band-pass optical filter.

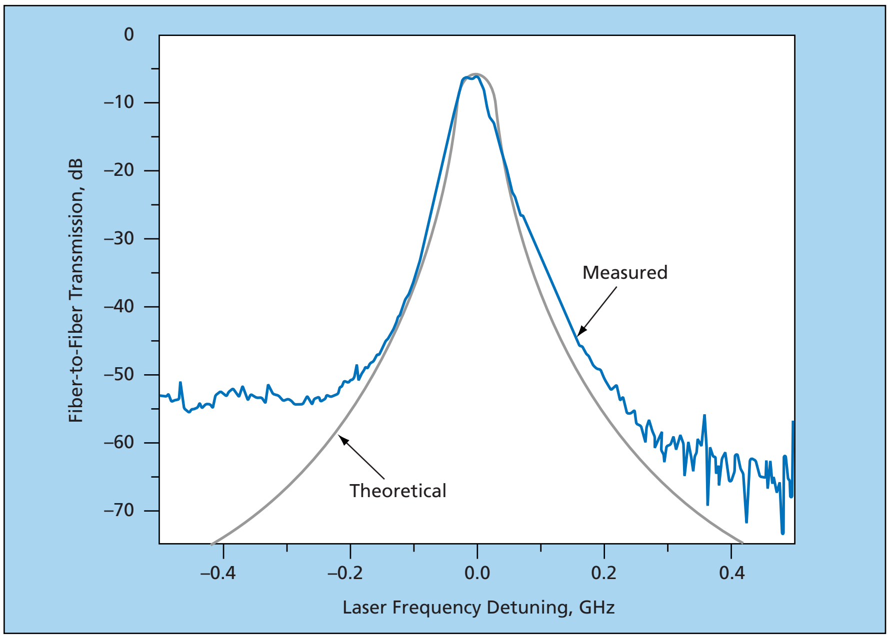


Figure 2. The **Measured Transmission Spectrum** of the filter was fitted with a Butterworth profile function $\gamma^6/[(\nu)^6+\gamma^6]$, where $\gamma$ = 29 MHz and $\nu$ is the laser frequency detuning (the difference between the laser frequency and the peak-transmission frequency).

Figure 1 depicts the optical layout of the present filter comprising an assembly of three coupled, tunable WGM resonators. Each WGM resonator is made from a disk of Z-cut $LiNbO_3$ of 3.3-mm diameter and 50-µm thickness. The perimeter of the disk is polished and rounded to a radius of curvature of 40 µm. The free spectral range of each WGM resonator is about 13.3 GHz. Gold coats on the flat faces of the disk serve as electrodes for exploiting the electro-optical effect in $LiNbO_3$ for tuning. There is no metal coat on the rounded perimeter region, where the whispering-gallery modes propagate. Light is coupled from an input optical fiber into the whispering-gallery modes of the first WGM resonator by means of a diamond prism. Another diamond prism is used to couple light from the whispering-gallery modes of the third WGM resonator to an output optical fiber.

The filter operates at a nominal wavelength of 1,550 nm and can be tuned over a frequency range of ±12 GHz by applying a potential in the range of ±150 V to the electrodes. The insertion loss (the loss between the input and output coupling optical fibers) was found to be repeatable at 6 dB. The resonance quality factor ($Q$) of the main sequence of resonator modes was found to be $5 \times 10^6$, which corresponds to a bandwidth of 30 MHz. The filter can be shifted from one operating frequency to another within a tuning time ≤30 µs. The transmission curve of the filter at frequencies near the middle of the passband closely approximates a theoretical third-order Butterworth filter profile, as shown in Figure 2.

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# Dynamic Pupil Masking for Phasing Telescope Mirror Segments

## Piston and tilt adjustments could be performed more efficiently.

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A method that would notably include dynamic pupil masking has been proposed as an enhanced version of a prior method of phasing the segments of a primary telescope mirror. The method would apply, more specifically, to a primary telescope mirror that comprises multiple segments mounted on actuators that can be used to tilt the segments and translate them along the nominal optical axis to affect wavefront control in increments as fine as a fraction of a wavelength of light. An apparatus (see figure) for implementing the proposed method would be denoted a dispersed-