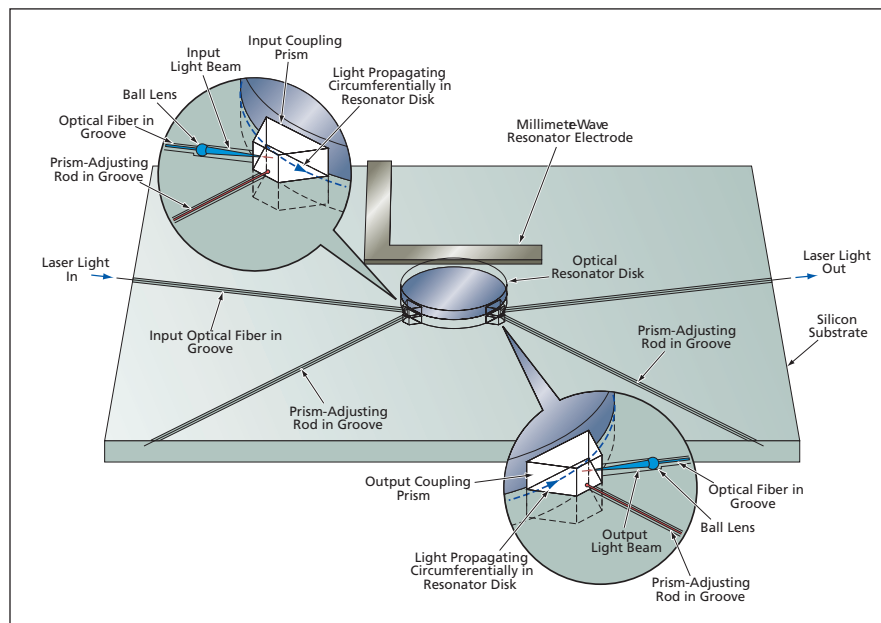


Laser light is introduced via the input optical fiber and focused into the input coupling prism. The input coupling prism is positioned near (but not in contact with) the resonator disk so that by means of evanescent-wave coupling, the input laser light in the prism gives rise to laser light propagating circumferentially in guided modes in the resonator disk. Similarly, a portion of the circumferentially propagating optical power is extracted from the disk by evanescent-wave coupling from the disk to the output coupling prism, from whence the light passes through the collimating ball lens into the output optical fiber.

The lens-tipped optical fibers must be positioned at a specified focal distance from the prisms. The optical fibers and the prisms must be correctly positioned relative to the resonator disk and must be oriented to obtain the angle of incidence ( $55^\circ$  in the prototype) required for evanescent-wave coupling of light into and out of the desired guided modes in the resonator disk. To satisfy all these requirements, precise alignment features are formed in the silicon substrate by use of a conventional wet-etching process. These features include a 5-mm-diameter, 50- $\mu\text{m}$ -deep cavity that holds the disk; two trapezoidal-cross-section recesses for the prisms; and two grooves that hold the optical fibers at the correct positions and angles relative to the prisms and disk. The fiber grooves contain abrupt tapers, near



**Optical Components** of a millimeter-wave photonic receiver are kept in alignment by mounting them in precise recesses in a silicon substrate.

the prisms, that serve as hard stops for positioning the lenses at the focal distance from the prisms.

There are also two grooves for prism-adjusting rods. The design provides a little slack in the prism recesses for adjusting the positions of the prisms by means of these rods to optimize the optical coupling.

*This work was done by Hung Nguyen, John Pouch, and Felix Miranda of Glenn*

*Research Center, and Anthony F. Levi of the University of Southern California. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17694-1.*

## **Diffraction Combiner of Single-Mode Pump Laser-Diode Beams** Multiple beams can be combined without inducing multifrequency lasing.

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

An optical beam combiner now under development would make it possible to use the outputs of multiple single-mode laser diodes to pump a neodymium: yttrium aluminum garnet (Nd:YAG) non-planar ring oscillator (NPRO) laser while ensuring that the laser operates at only a single desired frequency. Heretofore, an Nd:YAG NPRO like the present one has been pumped by a single multimode laser-diode beam delivered via an optical fiber. It would be desirable to use multiple pump laser diodes to increase reliability beyond that obtainable from a single pump laser diode. However, as explained below, simplistically coupling multiple multimode laser-diode beams through a fiber-optic combiner would entail a significant reduction in cou-

pling efficiency, and lasing would occur at one or more other frequencies in addition to the single desired frequency.

Figure 1 schematically illustrates the principle of operation of a laser-diode-pumped Nd:YAG NPRO. The laser beam path is confined in a Nd:YAG crystal by means of total internal reflections on the three back facets and a partial-reflection coating on the front facet. The wavelength of the pump beam — 808 nm — is the wavelength most strongly absorbed by the Nd:YAG crystal. The crystal can lase at a wavelength of either 1,064 nm or 1,319 nm — which one depending on the optical coating on the front facet. A thermal lens effect induced by the pump beam enables stable lasing in the lowest-order transverse

electromagnetic mode (the  $\text{TEM}_{00}$  mode). The frequency of this laser is very stable because of the mechanical stability of the laser crystal and the unidirectional nature of the lasing. The unidirectionality is a result of the combined effects of (1) a Faraday rotation induced by an externally applied magnetic field and (2) polarization associated with non-normal incidence and reflection on the front facet.

In order to restrict lasing to a single frequency, it is necessary to confine the pump beam within the region occupied by the  $\text{TEM}_{00}$  mode of the NPRO laser beam near the front facet inside the crystal. In practice, this means that the pump beam must be focused to within a given solid angle ( $\Omega$ ) and area ( $A$ ). [If a

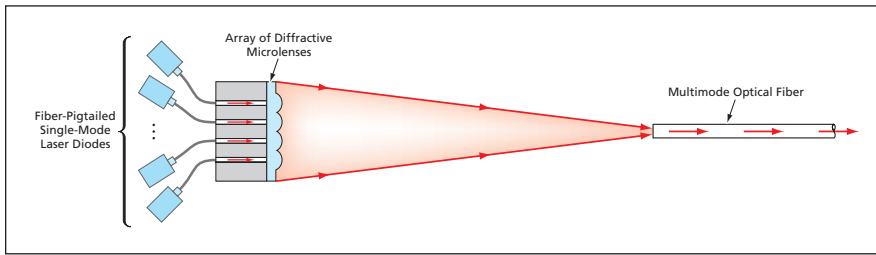


Figure 2. **Multiple Single-Mode Laser-Diode Beams** are focused onto a single narrow spot by use of an array of diffractive microlenses.

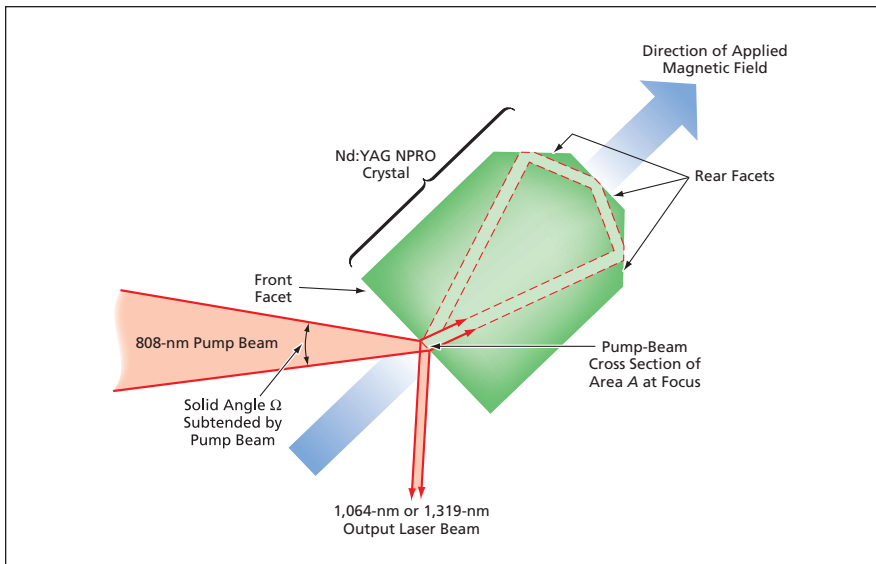


Figure 1. A **Pump Beam of Solid Angle  $\Omega$**  has a cross section of area  $A$  at incidence upon the front facet of an Nd:YAG NPRO laser crystal.

given pump beam has a larger  $A$  or larger  $\Omega$  but its  $A\Omega$  is equal to or less than the maximum  $A\Omega$  for single-frequency lasing in the crystal, then an imaging lens can be used to trade  $A$  against  $\Omega$  so that both  $A$  and  $\Omega$  are equal to or smaller than the maximum values for single-frequency lasing. It is possible to do this because it is a basic principle of optics that  $A\Omega$  is preserved in imaging by a lens.]

The  $A\Omega$  of a commercial multimode 808-nm laser diode of the type used

heretofore is not axisymmetric: instead, it is elliptically distributed about the optical axis and, hence, does not match the circular distribution of a multimode fiber of the type used heretofore to deliver a pump beam. As a result of this mismatch,  $A\Omega$  for the pump beam emerging from the output end of the fiber is increased, typically to near the maximum single-frequency-lasing value in at least one of the planes containing the principal axes of the elliptical distribution. Consequently, it is difficult or

impossible to maintain single-frequency lasing when combining the beams from two or more multimode laser diodes.

In the present approach (see Figure 2), the beams from multiple fiber-pigtailed single-mode laser diodes are coupled to single-mode optical fibers that have been placed together in a hexagonal-close-packing planar array. An array of diffractive microlenses, custom-designed and fabricated on a glass substrate by electron-beam lithography, is placed in front of the fiber array. The custom design and position of the lens array are chosen, according to the precisely measured actual positions of the fibers, so that the single-mode beams emerging from all the single-mode optical fibers are focused on the same small circular spot centered on the input face of a suitable multimode optical fiber. In use, the beam emerging from the output end of the multimode fiber would be focused onto the front facet of an Nd:YAG NPRO crystal in the usual way. It is anticipated that the  $A\Omega$  of the pump light thus incident on the crystal would be less than the maximum single-frequency-lasing value.

*This work was done by Duncan Liu, Daniel Wilson, Yueming Qiu, and Siamak Forouhar of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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*Refer to NPO-42411, volume and number of this NASA Tech Briefs issue, and the page number.*

## **Wide-Band, High-Quantum-Efficiency Photodetector**

**This device could detect single photons.**

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

A design has been proposed for a photodetector that would exhibit a high quantum efficiency (as much as 90 percent) over a wide wavelength band, which would typically be centered at a wavelength of 1.55  $\mu\text{m}$ . This and similar photodetectors would afford a capability

for detecting single photons — a capability that is needed for research in quantum optics as well as for the practical development of secure optical communication systems for distribution of quantum cryptographic keys.

The proposed photodetector would

be of the hot-electron, phonon-cooled, thin-film superconductor type. The superconducting film in this device would be a meandering strip of niobium nitride. In the proposed photodetector, the quantum efficiency would be increased through incorporation of opti-