

much larger set of molecular-structure descriptors by means of principal-component analysis and (2)  $K_0$  values for that compound in two different drift gases.

In a numerical-simulation test of the method, the neural network was trained

by use of descriptors,  $K_0$  values, and molecular masses pertaining to 65 organic compounds, then interrogated by use of descriptors and  $K_0$  values pertaining to 10 other organic compounds. The molecular masses generated by the neural network were found to differ from the

correct values by root-mean-square errors of no more than a few percent.

*This work was done by Tuan Duong and Isik Kanik of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-44576*

## Optical Displacement Sensor for Sub-Hertz Applications

NASA's Jet Propulsion Laboratory, Pasadena, California.

A document discusses a sensor made from off-the-shelf electro-optical photodiodes and electronics that achieves  $20 \text{ nm}/(\text{Hz})^{1/2}$  displacement sensitivity at 1 mHz. This innovation was created using a fiber-coupled laser diode (or Nd:YAG) through a collimator and an aperture as the illumination source. Together with a germanium quad photodiode, the above-mentioned displace-

ment sensor sensitivities have been achieved. This system was designed to aid the Laser Interferometer Space Antenna (LISA) with microthruster tests and to be a backup sensor for monitoring the relative position between a proof mass and a spacecraft for drag-free navigation. The optical displacement sensor can be used to monitor any small displacement from a remote loca-

tion with minimal invasion on the system.

*This work was done by Alexander Abramovici, Meng P. Chiao, and Frank G. Dekens of Caltech for NASA's Jet Propulsion Laboratory. For further information, download the Technical Support Package (free white paper) at [www.techbriefs.com/tsp](http://www.techbriefs.com/tsp) under the Physical Sciences category. NPO-30681*

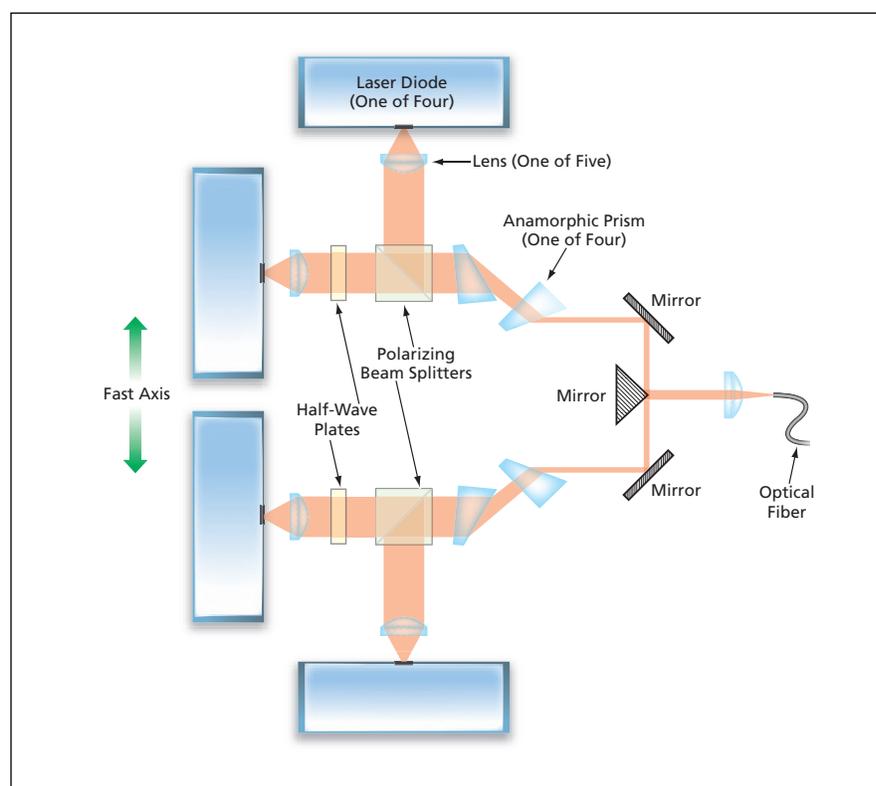
## Polarization/Spatial Combining of Laser-Diode Pump Beams

Four beams are combined into two, which are then combined into one.

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The figure depicts a breadboard version of an optical beam combiner that makes it possible to use the outputs of any or all of four multimode laser diodes to pump a non-planar ring oscillator (NPRO) laser. This apparatus could be an alternative to the one described in the immediately preceding article. Whereas that one utilizes spatial (beam-shaping) beam-combining techniques, this one utilizes a combination of polarization and spatial beam-combining techniques. In both that case and this one, the combined multiple laser-diode pump beams are coupled into an optical fiber for delivery to the NPRO pump optics.

As described in more detail in the immediately preceding article, the output of each laser diode has a single-mode profile in the meridional plane containing an axis denoted the "fast" axis and a narrower multimode profile in the orthogonal meridional plane, which contains an axis denoted the "slow" axis. Also as before, one of the purposes served by the beam-combining optics is to reduce the fast-axis numerical aperture (NA) of the laser-diode output to match the NA of the optical fiber. Along the slow axis, the unmodified laser-diode NA is already well



Four Laser-Diode Beams are polarization-combined into two, then narrowed along the fast axis, then combined into one beam incident on an end face of an optical fiber.

matched to the fiber-optic NA, so no further slow-axis beam shaping is needed.

In this beam combiner (see figure), the laser-diode outputs are collimated by aspherical lenses, then half-wave plates and polarizing beam splitters are used to combine the four collimated beams into two beams. Spatial combination of the two beams and coupling into the optical fiber is effected by use of anamorphic prisms, mirrors, and a focusing lens. The anamorphic prisms are critical elements in the NA-matching scheme, in that they reduce

the fast-axis beam width to 1/6 of its original value. Inasmuch as no slow-axis beam shaping is needed, the collimating and focusing lenses are matched for 1:1 imaging. Because these lenses are well corrected for infinite conjugates, the combiner offers diffraction-limited performance along both the fast and slow axes.

*This work was done by Paul Gelsinger and Duncan Liu of Caltech for NASA's Jet Propulsion Laboratory.*

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## Spatial Combining of Laser-Diode Beams for Pumping an NPRO

Multiple multimode beams are efficiently combined into one optical fiber.

NASA's Jet Propulsion Laboratory, Pasadena, California

A free-space optical beam combiner now undergoing development makes it possible to use the outputs of multiple multimode laser diodes to pump a neodymium-doped yttrium aluminum garnet (Nd:YAG) non-planar ring oscillator (NPRO) laser while ensuring that the laser operates at only a single desired frequency. This optical beam combiner serves the same purpose as does the one described in "Diffractive Combiner of Single-Mode Pump Laser-Diode Beams" (NPO-42411), NASA Tech Briefs, Vol. 31, No. 5 (May 2007), page 16a. Although the principles of design and operation of the present and prior beam combiners are not identical, they are so closely related that it is necessary to devote the next four paragraphs to reiteration of a substantial portion of the cited prior article in order to give meaning to a description of the present beam combiner.

Heretofore, a 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 coupling 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

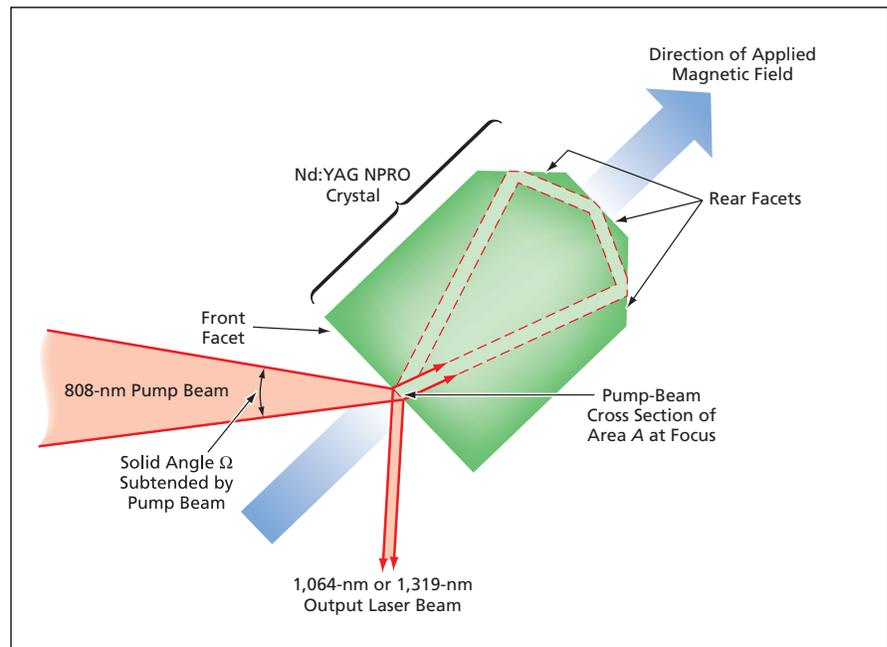


Figure 1. A Pump Beam of Solid Angle  $\Omega$  has a cross section of area  $A$  at incidence upon the front facet of a Nd:YAG NPRO laser crystal.

the three back facets and an optical 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.

In order to restrict lasing to a single frequency, it is necessary to confine the pump beam within the region occupied by the  $TEM_{00}$  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 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