



## Recirculation of Laser Power in an Atomic Fountain

Optical and electronic subsystems of a frequency standard can be simplified.

NASA's Jet Propulsion Laboratory, Pasadena, California

A new technique for laser-cooling atoms in a cesium atomic fountain frequency standard relies on recirculation of laser light through the atom-collection region of the fountain. The recirculation, accomplished by means of reflections from multiple fixed beam-splitter cubes, is such that each of two laser beams makes three passes. As described below, this recirculation scheme offers several advantages over prior designs, including simplification of the laser system, greater optical power throughput, fewer optical and electrical connections, and simplification of beam power balancing.

A typical laser-cooled cesium fountain requires the use of six laser beams arranged as three orthogonal pairs of counter-propagating beams to decelerate the atoms and hold them in a three-dimensional optical trap in vacuum. Typically, these trapping/cooling beams are linearly polarized and are positioned

and oriented so that (1) counter-propagating beams in each pair have opposite linear polarizations and (2) three of the six orthogonal beams have the sum of their propagation directions pointing up, while the other three have the sum of their propagation directions pointing down.

In a typical prior design, two lasers are used — one to generate the three “up” beams, the other to generate the three “down” beams. For this purpose, the output of each laser is split three ways, then the resulting six beams are delivered to the vacuum system, independently of each other, via optical fibers.

The present recirculating design also requires two lasers, but the beams are not split before delivery. Instead, only one “up” beam and one oppositely polarized “down” beam are delivered to the vacuum system, and each of these beams is sent through the collection region three times. The polarization of each beam on

each pass through the collection region is set up to yield the same combination of polarization and propagation directions as described above.

In comparison with the prior design, the present recirculating design utilizes the available laser light more efficiently, making it possible to trap more atoms at a given laser power or the same number of atoms at a lower laser power. The present design is also simpler in that it requires fewer optical fibers, fiber couplings, and collimators, and fewer photodiodes for monitoring beam powers. Additionally, the present design alleviates the difficulty of maintaining constant ratios among power levels of the beams within each “up” or “down” triplet.

*This work was done by Daphna G. Enzer, William M. Klipstein, and James D. Moore of NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).  
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## Simplified Generation of High-Angular-Momentum Light Beams

Inherent properties of a WGM resonator and optical fiber are exploited.

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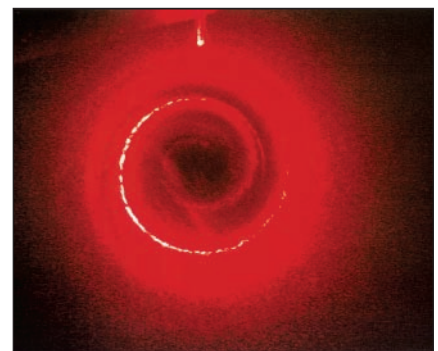
A simplified method of generating a beam of light having a relatively high value of angular momentum (see figure) involves the use of a compact apparatus consisting mainly of a laser, a whispering-gallery-mode (WGM) resonator, and optical fibers. The method also can be used to generate a Bessel beam. (“Bessel beam” denotes a member of a class of non-diffracting beams, so named because their amplitudes are proportional to Bessel functions of the radii from their central axes. High-order Bessel beams can have high values of angular momentum.)

High-angular-momentum light beams are used in some applications in biology and nanotechnology, wherein they are known for their ability to apply torque to make microscopic objects rotate.

High-angular-momentum light beams could also be used to increase bandwidths of fiber-optic communication systems. The present simplified method of generating a high-angular-momentum light beam was conceived as an alternative to prior such methods, which are complicated and require optical setups that include, variously, holograms, modulating Fabry-Perot cavities, or special microstructures.

The present simplified method exploits a combination of the complex structure of the electromagnetic field inside a WGM resonator, total internal reflection in the WGM resonator, and the electromagnetic modes supported by an optical fiber. The optical fiber used to extract light from the WGM resonator is made of fused quartz. The out-

put end of this fiber is polished flat and perpendicular to the fiber axis. The input end of this fiber is cut on a slant and placed very close to the WGM resonator at an appropriate position and



A Vortex is shown as it is generated by the apparatus. The red glowing stick at the top edge of the photo is a fused silica horn.

orientation. To excite the resonant whispering-gallery modes, light is introduced into the WGM resonator via another optical fiber that is part of a pigtailed fiber-optic coupler.

Light extracted from the WGM resonator is transformed into a high-angular-momentum beam inside the extraction optical fiber and this beam is emitted from the polished flat output end. By adjusting the geometry of this apparatus, it is possible to generate a va-

riety of optical beams characterized by a wide range of parameters. These beams generally have high angular momenta and can be of either Bessel or Bessel-related types.

*This work was done by Anatoliy Savchenkov, Lute Maleki, Andrey Matsko, Dmitry Strelakov, and Ivan Grudinin of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

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*Refer to NPO-42965, volume and number of this NASA Tech Briefs issue, and the page number.*

## Imaging Spectrometer on a Chip

**One integrated circuit would perform the functions of a conventional several-kilogram spectrometer.**

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A proposed visible-light imaging spectrometer on a chip would be based on the concept of a heterostructure comprising multiple layers of silicon-based photodetectors interspersed with long-wavelength-pass optical filters. In a typical application, this heterostructure would be replicated in each pixel of an image-detecting integrated circuit of

the active-pixel-sensor type (see figure).

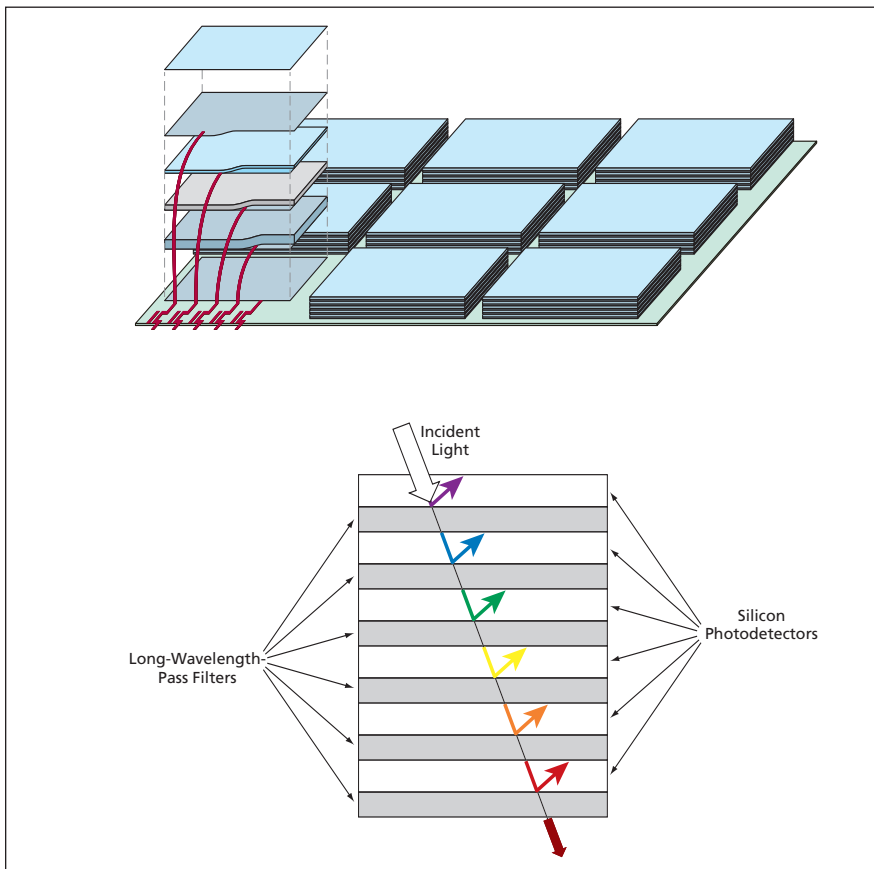
The design of the heterostructure would exploit the fact that within the visible portion of the spectrum, the characteristic depth of penetration of photons increases with wavelength. Proceeding from the front toward the back, each successive long-wavelength-pass filter would have a longer cutoff

wavelength, and each successive photodetector would be made thicker to enable it to absorb a greater proportion of incident longer-wavelength photons.

Incident light would pass through the first photodetector and encounter the first filter, which would reflect light having wavelengths shorter than its cutoff wavelength and pass light of longer wavelengths. A large portion of the incident and reflected shorter-wavelength light would be absorbed in the first photodetector.

The light that had passed through the first photodetector/filter pair of layers would pass through the second photodetector and encounter the second filter, which would reflect light having wavelengths shorter than its cutoff wavelength while passing light of longer wavelengths. Thus, most of the light reflected by the second filter would lie in the wavelength band between the cutoff wavelengths of the first and second filters. In a similar manner, each successive photodetector would detect, predominantly, light in a successively longer wavelength band bounded by the shorter cutoff wavelength of the preceding filter and the longer cutoff wavelength of the following filter.

*This work was done by Yu Wang, Be-dabrata Pain, Thomas Cunningham, and Xinyu Zheng of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-41125*



Each Pixel of an Active-Pixel Sensor would contain multiple photodetector/filter pairs operating at successively longer wavelengths.