

# Alpha-Voltaic Sources Using Diamond as Conversion Medium

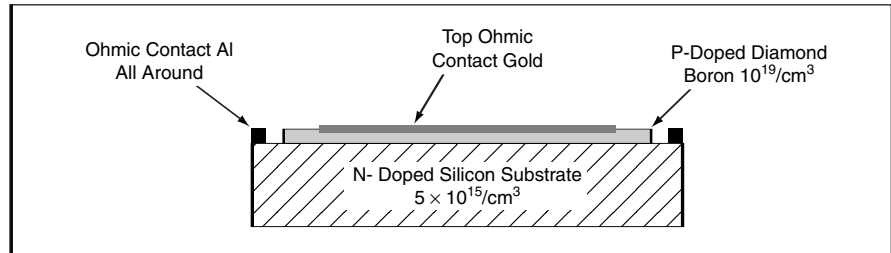
Compact, long-lived solid-state devices would tolerate wide temperature ranges.

NASA's Jet Propulsion Laboratory, Pasadena, California

A family of proposed miniature sources of power would exploit the direct conversion of the kinetic energy of  $\alpha$  particles into electricity in diamond semiconductor diodes. These power sources would function over a wide range of temperatures encountered in terrestrial and outer-space environments. These sources are expected to have operational lifetimes of 10 to 20 years and energy conversion efficiencies >35 percent.

A power source according to the proposal would include a pair of devices like that shown in the figure. Each device would contain Schottky and p/n diode devices made from high-band-gap, radiation-hard diamond substrates. The n and p layers in the diode portion would be doped sparsely ( $<10^{14} \text{ cm}^{-3}$ ) in order to maximize the volume of the depletion region and thereby maximize efficiency. The diode layers would be supported by an undoped diamond substrate.

The source of  $\alpha$  particles would be a thin film of  $^{244}\text{Cm}$  (half-life 18 years) sand-



This **Diamond Diode** is one of two that would be sandwiched together with a thin film of  $^{244}\text{Cm}$ , which is a source of  $\alpha$  particles. The sandwich structure would constitute an alpha-voltaic device.

wiched between the two paired devices. The sandwich arrangement would force almost every  $\alpha$  particle to go through the active volume of at least one of the devices. Typical  $\alpha$  particle track lengths in the devices would range from 20 to 30 microns. The  $\alpha$  particles would be made to stop only in the undoped substrates to prevent damage to the crystalline structures of the diode portions.

The overall dimensions of a typical source are expected to be about 2 by 2 by 1 mm. Assuming an initial  $^{244}\text{Cm}$  mass of 20 mg, the estimated initial out-

put of the source is 20 mW (a current of 20 mA at a potential of 1 V).

This work was done by Jagdish U. Patel, Jean-Pierre Fleuriel, and Elizabeth Kolawa of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Management Office-JPL at (818) 354-7770. Refer to NPO-30323.

# White-Light Whispering-Gallery-Mode Optical Resonators

Overlapping resonator modes are exploited to obtain wide, high-Q spectra.

NASA's Jet Propulsion Laboratory, Pasadena, California

Whispering-gallery-mode (WGM) optical resonators can be designed to exhibit continuous spectra over wide wavelength bands (in effect, white-light spectra), with ultrahigh values of the resonance quality factor ( $Q$ ) that are nearly independent of frequency. White-light WGM resonators have potential as superior alternatives to (1) larger, conventional optical resonators in ring-down spectroscopy, and (2) optical-resonator/electro-optical-modulator structures used in coupling of microwave and optical signals in atomic clocks. In these and other potential applications, the use of white-light WGM resonators makes it possible to relax the requirement of high-frequency stability of lasers, thereby enabling the use of cheaper lasers.

In designing a white-light WGM resonator, one exploits the fact that the density of the mode spectrum increases predictably with the thickness of the

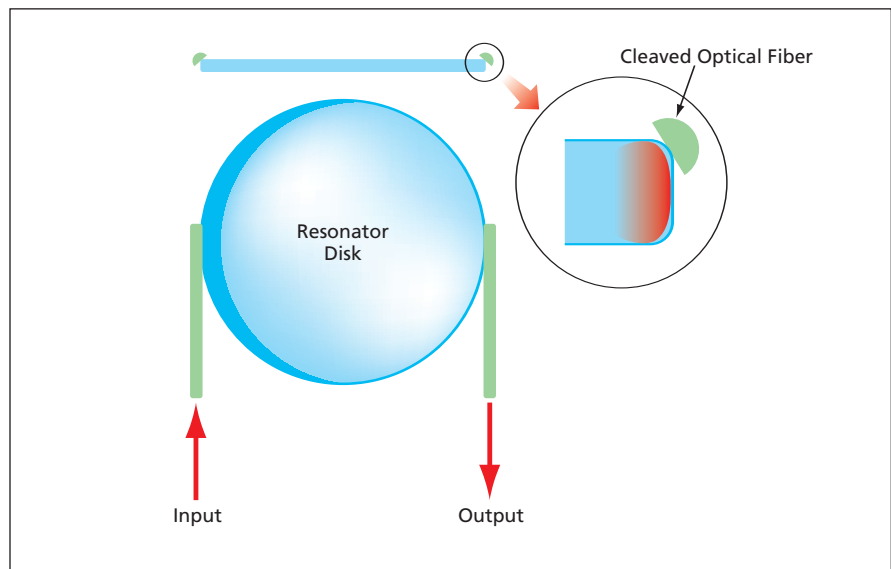


Figure 1. **Cleaved Optical Fibers** tangential to the rim of the resonator disk are used to couple light into and out of the disk. The fibers are shifted with respect to the middle of the rim to obtain a high degree of interaction with all the WGM modes.

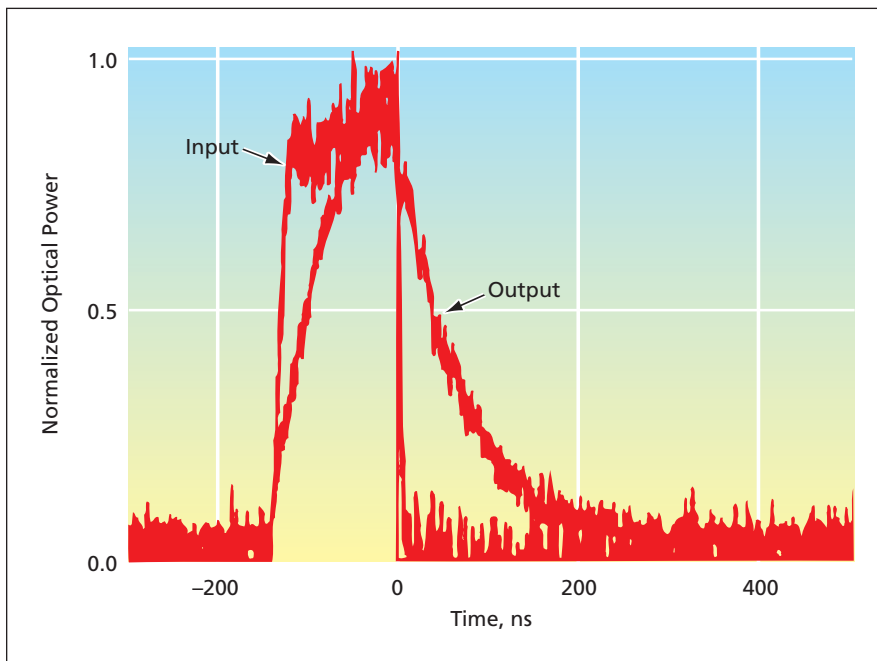


Figure 2. **Normalized Power Levels** of input and output pulses of light, as functions of time, were determined in the setup depicted in Figure 1. The small amplitude modulation in the ring-down tail was attributed to slight non-preservation of orthogonality between resonator modes — an artifact of the input/output coupling technique.

resonator disk. By making the resonator disk sufficiently thick, one can make the frequency differences between adjacent modes significantly less than the spectral width of a single mode, so that the spectral peaks of adjacent modes overlap, making the resonator spectrum essentially continuous. Moreover, inasmuch as the  $Q$  values of the various modes are deter-

mined primarily by surface Rayleigh scattering that does not depend on mode numbers, all the modes have nearly equal  $Q$ . By use of a proper coupling technique, one can ensure excitation of a majority of the modes.

For an experimental demonstration of a white-light WGM resonator, a resonator disk 0.5-mm thick and 5 mm in diameter was made from  $\text{CaF}_2$ . The

shape of the resonator and the fiber-optic coupling arrangement were as shown in Figure 1. The resonator was excited with laser light having a wavelength of 1,320 nm and a spectral width of 4 kHz. The coupling efficiency exceeded 80 percent at any frequency to which the laser could be set in its tuning range, which was >100-GHz wide.

The resonator response was characterized by means of ring-down tests in which the excitation was interrupted by a shutter having a rise and a fall time of 5 ns. The ring-down time of photodiodes and associated circuitry used to measure the interrupted excitation and the resonator output was <1 ns. Figure 2 shows the shapes of representative input and output light pulses. The average ring-down time was found to be 120 ns, corresponding to  $Q \approx 2 \times 10^8$ . The variations of  $Q$  with the laser carrier frequency were found to be <5 percent. Hence, the resonator was shown to have the desired “white light” properties.

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

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Management Office–JPL. Refer to NPO-42221.*