Tunable single-mode WGM resonators would be incorporated into optical spectrum analyzers as shown in the block diagram in Figure 1. The center of the spectral window of the spectrum analyzer will be tuned to the carrier frequency of interest. The rough snapshot of the signal under study will be taken. After that, the WGM filter will be inserted in front of the spectrum analyzer. The internal scanning of the spectrum analyzer will be switched off, while the WGM filter will be scanned through the frequency window. The narrow-band spectral features of the signal will be resolved as the result. In particular, for the purpose of measuring abundances of selected isotopes (e.g., isotopes of carbon) in compounds in outer space and in atmospheres of Earth and other planets, an instrument equipped according to the proposal could measure narrow (width < 10 MHz) optical spectral signatures of compounds (e.g., CO_2) containing such isotopes.

The advantageous spectral characteristics of WGM resonators include high resonance quality factors (see Figure 2) and clean spectra. In addition, relative to other tunable optical resonators that have similar free spectral ranges and Q values, tunable single-mode WGM resonators can be tuned over wider frequency bands and exhibit much greater rejection ratios. A tunable single-mode WGM resonator incorporated into a spectrum analyzer according to the proposal would have a power consumption of no more than a few milliwatts, would have a mass of about 100 g, would have no moving parts, and could be operated autonomously. In addition to being key components of contemplated new high-resolution optical spectrum analyzers, tunable single-mode WGM resonators could be retrofit to current optical spectrum analyzers to improve their performances.

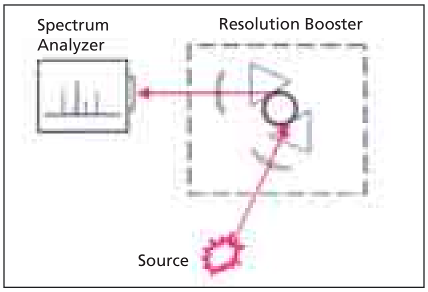

Figure 1. A **Resolution Booster** exploits the advantage of WGM resonators to increase spectral resolution at least three orders of magnitude.

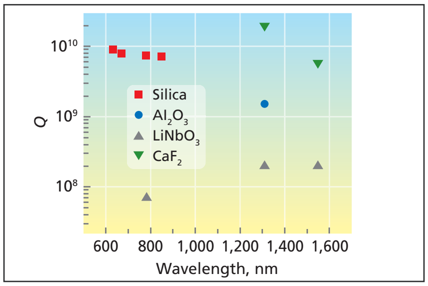

Figure 2. **These Resonance Quality Factors** (Q values) plotted versus wavelength were obtained from measurements on WGM resonators made of the indicated materials.

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

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Quantum-Well Thermophotovoltaic Cells

Conversion efficiencies more than twice those of prior thermophotovoltaic cells are expected.

Marshall Space Flight Center, Alabama

Thermophotovoltaic cells containing multiple quantum wells have been invented as improved means of conversion of thermal to electrical energy. The semiconductor bandgaps of the quantum wells can be tailored to be narrower than those of prior thermophotovoltaic cells, thereby enabling the cells to convert energy from longer-wavelength photons that dominate the infrared-rich spectra of typical thermal sources with which these cells would be used. Moreover, in comparison with a conventional single-junction thermophotovoltaic cell, a cell containing multiple narrow-bandgap quantum wells according to the invention can convert energy from a wider range of wavelengths. Hence, the invention increases the achievable thermal-to-electrical energy-conversion efficiency. These thermophotovoltaic cells are expected to be especially useful for extracting electrical energy from combustion, waste-heat, and nuclear sources having temperatures in the approximate range from 1,000 to 1,500 °C.

In its original form, the invention applies to the $In_xGa_{1-x}As$ ($0<x<1$)-and-InP material system. In principle, it is equally applicable to any narrow-bandgap semiconductor material system that is amenable to the growth of lattice-matched multiple quantum wells on suitable substrates. A cell according to the invention is best described with reference to the corresponding conventional $In_xGa_{1-x}As$ thermophotovoltaic cell, which is an electron-acceptor-doped/intrinsic/electron-donor-doped (p/i/n) $In_{0.47}Ga_{0.53}As$ cell lattice-matched to an InP substrate. In the cell according to the invention, instead of the intrinsic (undoped) region, there are multiple strained, lattice-matched, narrow-bandgap quantum wells comprising layers of $In_xGa_{1-x}As$ ($x>0.6$) interspersed with layers of $In_{0.47}Ga_{0.53}As$. It has been estimated that for black-body thermal sources having temperatures between 1,000 and 1,500 °C, the energy-conversion efficiencies of thermophotovoltaic cells according to the invention can be more than twice those of the corresponding conventional $In_xGa_{1-x}As$ thermophotovoltaic cells.

An appropriate choice of the number of quantum wells and the thicknesses of the individual quantum-well layers (typically of the order of a few nanometers) in conjunction with the selection of the quantum-well materials makes it possible to prevent the generation of lattice-mismatch crystal defects in the quantum-well layers. Thus, it is possible to prevent the degradation of crystalline quality and thereby prevent the consequent degradation of electronic performance associated with the fabrication of thicker conventional lattice-mismatched devices. Inasmuch as conventional $In_xGa_{1-x}As$ thermophotovoltaic cells are already manufactured by techniques compatible with the growth of multiple quantum wells, little additional expense would be incurred by adding quantum-well-growth steps to conventional manufacturing processes.

This work was done by Alex Freudlich and Alex Ignatiev of the University of Houston for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32545-1