



A Technique for Adjusting Eigenfrequencies of WGM Resonators

NASA's Jet Propulsion Laboratory, Pasadena, California

A simple technique has been devised for making small, permanent changes in the eigenfrequencies (resonance frequencies) of whispering-gallery-mode (WGM) dielectric optical resonators that have high values of the resonance quality factor (Q). The essence of the technique is to coat the resonator with a thin layer of a transparent polymer having an index of refraction close to that of the resonator material.

Successive small frequency adjustments can be made by applying successive coats. The technique was demonstrated on a calcium fluoride resonator

to which successive coats of a polymer were applied by use of a hand-made wooden brush. To prevent temperature-related frequency shifts that could interfere with the verification of the effectiveness of this technique, the temperature of the resonator was stabilized by means of a three-stage thermoelectric cooler. Measurements of the resonator spectrum showed the frequency shifts caused by the successive coating layers.

This work was done by Dmitry Strelakov, Anatoliy Savchenkov, Lute Maleki, Andrey Matsko, Vladimir Ilchenko, and Jan Martin 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-44383, volume and number of this NASA Tech Briefs issue, and the page number.

Low-Pressure, Field-Ionizing Mass Spectrometer

This lightweight, low-power instrument functions well in a low-grade (partial) vacuum.

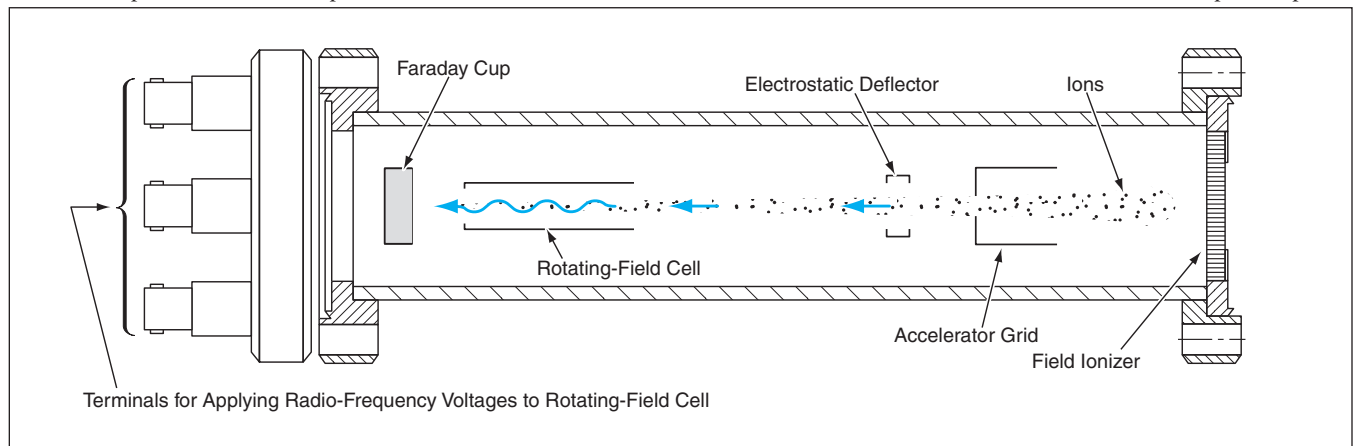
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A small mass spectrometer utilizing a miniature field ionization source is now undergoing development. It is designed for use in a variety of applications in which there are requirements for a lightweight, low-power-consumption instrument that can analyze the masses of a wide variety of molecules and ions. The device can operate without need for a high-vacuum, carrier-gas feed radioactive ionizing source, or thermal ionizer. This mass spectrometer can operate ei-

ther in the natural vacuum of outer space or on Earth at any ambient pressure below 50 torr (below about 6.7 kPa) — a partial vacuum that can easily be reached by use of a small sampling pump. This mass spectrometer also has a large dynamic range — from singly charged small gas ions to deoxyribonucleic acid (DNA) fragments larger than 10^4 atomic mass units — with sensitivity adequate for detecting some molecules and ions at relative abundances of less

than one part per billion.

This instrument (see figure) includes a field ionizer integrated with a rotating-field mass spectrometer (RFMS). The field ionizer effects ionization of a type characterized as "soft" in the art because it does not fragment molecules or initiate avalanche arcing. What makes the "soft" ionization mode possible is that the distance between the ionizing electrodes is less than mean free path for ions at the maximum anticipated operat-



A Field Ionizer and a Rotating-Field Mass Spectrometer are integrated into a single instrument that has a mass <1 kg and a power consumption <5 W.

ing pressure, so that the ionizer always operates on the non-breakdown side of the applicable Paschen curve (a standard plot of breakdown potential on the ordinate and pressure electrode separation on the abscissa).

The field ionizer in this instrument is fabricated by micromachining a submicron-thick membrane out of an electrically nonconductive substrate, coating the membrane on both sides to form electrodes, then micromachining small holes through the electrodes and membrane. Because of the submicron electrode separation, even a potential of only 1 V applied between the electrodes gives rise to an electric field with a strength of in excess of a megavolt per meter — strong enough to ionize any gas molecules passing through the holes.

An accelerator grid and an electrostatic deflector focus the ions from the field ionizer into the rotating-field cell of the RFMS. The potentials applied to the electrodes of the cell to generate the ro-

tating electric field typically range from 1 to 13 V. The ions travel in well-defined helices within this cell, after which they are collected in a Faraday cup. The mass of most of the molecules reaching the Faraday cup decreases with increasing frequency of rotation of the electric field in the cell. Therefore, the frequency of rotation of the electric field is made to vary in order to scan through a desired range of ion masses: For example, light-weight gas molecules are scanned at frequencies in the megahertz range, while DNA and other large organic molecules are scanned at kilohertz frequencies.

The current of accelerated ions is attenuated by collisions between these ions and the much slower (thermal) background gas molecules. In a typical case of operation at 5 Torr, an initial ion-beam current of about 10 nA would be attenuated to about 40 pA. However, the instrument could still afford adequate sensitivity because the electric current of ions collected by the Fara-

day cup is read by use of an electrometer that can resolve a current of the order of a femtoampere. In certain cases of low vacuum (10^{-5} Torr), a channel electron multiplier (CEM) plate could also be utilized in a single ion detection mode.

This work was done by Frank Hartley and Steven Smith 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-30245, volume and number of this NASA Tech Briefs issue, and the page number.

Modifying Operating Cycles To Increase Stability in a LITS

Microwave-interrogation time can be increased while maintaining optimum lamp duty cycle.

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The short-term instability in the frequency of a linear-ion-trap frequency standard (LITS) can be reduced by modifying two cycles involved in its operation: (1) the bimodal (bright/dim) cycle of a plasma discharge lamp used for state preparation and detection and (2) a microwave-interrogation cycle. The purpose and effect of the modifications is to enable an increase in the microwave-interrogation cycle time, motivated by the general principle that the short-term uncertainty or instability decreases with increasing microwave-interrogation time. Stated from a slightly different perspective, the effect of modifications is to enable the averaged LITS readings to settle to their long-term stability over a shorter total observation time.

The basic principles of a LITS were discussed in several *NASA Tech Briefs* articles. Here are recapitulated only those items of background information necessary to place the present modifications in context. A LITS includes a microwave local oscillator, the frequency of which is stabilized by comparison with the frequency of a ground-state hyperfine transition of

$^{199}\text{Hg}^+$ ions. In a LITS of the type to which the modifications apply, the comparison involves a combination of optical and microwave excitation and interrogation of the ions in two collinear ion traps: a quadrupole trap wherein the optical excitation used for state preparation and detection takes place, and a multipole (e.g., 12-pole) trap wherein the microwave interrogation of the "clock" transition takes place. The ions are initially loaded into the quadrupole trap and are thereafter shuttled between the two traps. This concludes the background information.

One source of systematic frequency error is an AC Stark shift caused by light present during microwave interrogation. To minimize this source of error, most stray light is suppressed by design, and heretofore, the microwave-interrogation time has been limited to the dim portion of the bimodal lamp cycle. It has now been learned that it is not necessary to limit the microwave interrogation to the dim portion of the lamp cycle because the separation of the two collinear ion traps is such that very little light from the lamp reaches the multipole

trap wherein the microwave interrogation takes place. Indeed, the lamp-light-attenuation factor associated with the separation of the collinear ion traps is greater than the ratio between the bright and dim lamp intensities. The abandonment of this limitation creates an option to operate the lamp at an optimum duty cycle and to perform the microwave interrogation for a longer time, as described next.

The equilibrium temperature of the lamp depends on the ambient temperature and the lamp duty cycle. For each lamp, it is possible to empirically determine an equilibrium temperature (and, hence, a duty cycle) that is optimum in the sense that it maximizes the signal-to-noise ratio (SNR) during microwave interrogation. Hence, one of the modifications is to set the bimodal lamp operating cycle to the optimum duty cycle. The other modification is to increase the microwave-interrogation time to a desired integer multiple of the lamp cycle time. (The multiple must have an integer value because it is still necessary to synchronize the optical and microwave operating cycles.) The size of the integer multiple is subject to an over-