

June 3, 1969

F. J. ROSENBAUM  
DIELECTRIC CAVITY RESONATOR

3,448,379

Filed May 18, 1964

FIG. 1.

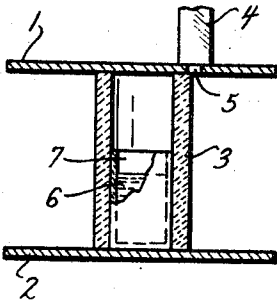


FIG. 2.

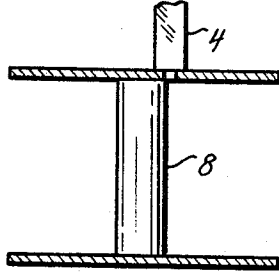


FIG. 3.

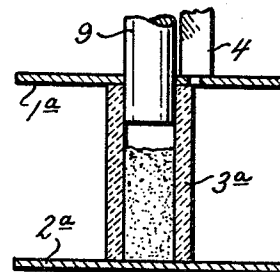


FIG. 4.

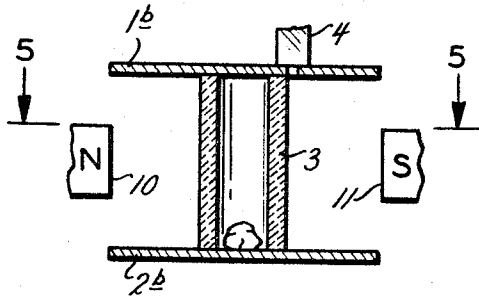


FIG. 5.

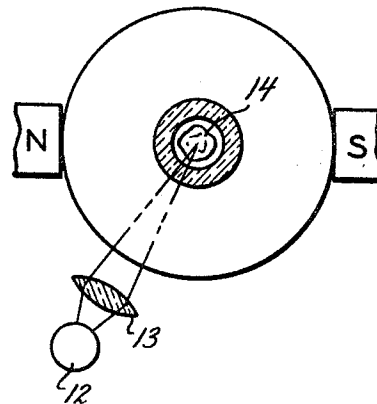


FIG. 6.

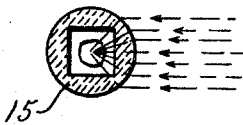


FIG. 7.

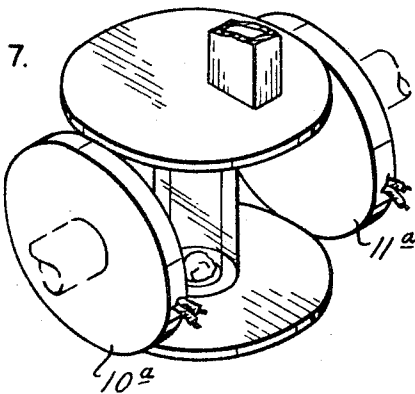
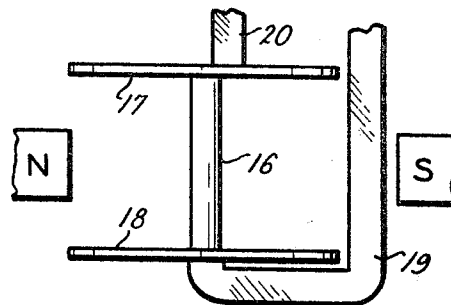


FIG. 8.



INVENTOR.  
FRED J. ROSENBAUM

BY  
*Gravelly, Lieder & Woodruff*  
ATTORNEYS

1

3,448,379

## DIELECTRIC CAVITY RESONATOR

Fred J. Rosenbaum, Chesterfield, Mo., assignor to  
McDonnell Douglas Corporation, St. Louis, Mo.,  
a corporation of Maryland

Filed May 18, 1964, Ser. No. 367,929

Int. Cl. G01r 27/04

U.S. Cl. 324—58

18 Claims

### ABSTRACT OF THE DISCLOSURE

An open sided dielectric cavity structure defined by spaced conducting plates and a dielectric member extending between said plates, and means for introducing microwave energy into the cavity adjacent to the dielectric member including a waveguide positioned adjacent to one of the dielectric plates and coupled to the space between the plates through a coupling opening. The subject cavity structure may also include a second waveguide adjacent the other spaced plate and coupled to the space therebetween through another coupling opening to introduce microwave energy into the cavity at a different frequency, and the subject structure may also include means for introducing other types of energy into the cavity including magnetic and radiation energy.

The present invention relates generally to resonant devices and the like and more particularly to a cavity resonating device employing dielectric means in the construction and operation thereof.

Numerous devices are in existence which employ resonant chambers or cavities as parts thereof. These devices are used for many different purposes and particularly for relatively high frequency applications, and various means are employed for stimulating or exciting the known devices to perform some purpose. However, the means used in the construction of known cavities are usually relatively impervious to certain kinds of stimulations and this has limited their usefulness. For these and other reasons known cavity resonator devices have been limited in their usefulness, unsatisfactory for many purposes and too expensive for many applications.

These and other disadvantages and shortcomings of known cavity resonators are overcome by the present device which includes an open sided resonant cavity device constructed of two spaced electrically conductive plate members with a dielectric member extending therebetween, and with means for stimulating or exciting the cavity including a microwave energy source and a wave guide for feeding energy from said source into the cavity. The shape and dimensions of the cavity forming members including the dielectric member effect the operating and other characteristics of the device. Furthermore, the subject device is more versatile than known cavity resonators and is particularly well suited for examining materials by spectroscopic and other methods and can be used for many other purposes such as in radar, microwave telecopy, and maser applications to name a few.

It is therefore a principal object of the present invention to provide relatively inexpensive means for forming a resonant cavity which is suitable for spectroscopic and other uses.

2

It is another important object to increase the versatility and usefulness of devices employing resonant cavities.

Another object is to provide a resonant cavity for use in examining and analyzing substances as by spectroscopic techniques in which the substances being examined can be subjected to or stimulated by a great variety of energy forms.

Another object is to provide an improved resonant cavity for microwave spectroscopy including means for obtaining more information from spectroscopic examinations.

Another object is to provide improved means for introducing energy into a resonant cavity.

Another object is to provide improved means for tuning and otherwise varying and adjusting the characteristics of cavity resonators.

Another object is to provide improved means for orienting a sample in a resonant cavity.

Another object is to provide a resonant cavity that is easily adapted for operation at low temperatures and in vacuums.

Another object is to provide a resonator that can be made relatively large even at very high frequencies.

Another object is to provide an improved maser construction including improved pumping means therefor.

These and other objects and advantages of the present invention will become apparent after considering the following detailed specification which discloses several preferred embodiments thereof in conjunction with the accompanying drawing, wherein:

FIG. 1 is a fragmentary cross-sectional view of a cavity resonator device constructed according to the present invention;

FIG. 2 is a side elevational view partly in section showing a modified form of the subject cavity resonator device;

FIG. 3 is a cross-sectional view similar to FIG. 1 of still another modified form of the subject device;

FIG. 4 is a cross-sectional view similar to FIG. 1 but including other excitation means therefor;

FIG. 5 is a cross-sectional view taken on line 5—5 of FIG. 4 and including still other excitation means;

FIG. 6 is a cross-sectional view showing a modified form of dielectric element per se for use on the subject device;

FIG. 7 is a perspective view showing yet another form of the subject device; and

FIG. 8 is a side elevational view showing yet another modified form of the subject device.

Referring to the drawing by reference numbers, the numbers 1 and 2 identifying two spaced electrically conductive plates of predetermined size and shape. A tubular member 3 of dielectric material extends between the plates and may provide mechanical support but its main purpose is to establish a resonant condition. The physical characteristics of the members 1, 2 and 3 determine the operating or resonant frequency and the quality factor Q of the cavity. It is essential to the operation of the device as a resonator that the dielectric member 3 be constructed of a non-conductive dielectric material because otherwise no resonance would occur. The physical characteristics of the members, however, can be varied considerably without changing the nature of the device as will be shown.

The dielectric tube 3 and the two spaced conductive

plates 1 and 2 operate as a high Q microwave resonant cavity, the frequency of which is determined by the spacing between the plates 1 and 2, the inside and outside diameters of the tube 3 and the dielectric constant of the tube material.

Microwave energy is introduced into the resonant cavity between the plates 1 and 2 adjacent to the tube 3 by means of a suitable wave guide 4 which communicates with the cavity through a coupling hole 5 in the plate 1. The location of the wave guide 4 and of the coupling hole 5 within limits are not critical and can be varied. For example, the coupling hole 5 can be located in an area of the plate 1 defined by the tube 3, or it can be located outside of this region. It can even be located in alignment with the wall of the tube 3. The microwave energy introduced into the cavity through the coupling hole 5 can also be introduced within a relatively wide range of microwave frequencies, as for example, from about 1 gc. to about 500 gc. The location of the coupling hole 5 and the orientation of the input energy feed wave guide associated therewith will also have an effect on the operating characteristics of the device including determining the mode of its microwave resonance. Other coupling configurations are also possible.

In the particular form of the invention shown in FIG. 1 the device is constructed specifically for examining or analyzing substances, and the dielectric member 3 is shown to be tubular in shape. It can also be constructed of transparent or of opaque material. In this particular construction the tube 3 is used to contain a sample substance 6 to be examined, and the sample 6 can be in a solid, liquid or gaseous form. The sample is examined or analyzed by being subjected to predetermined stimulations such as microwave stimulation, magnetic stimulation, light stimulation and other forms of stimulation. Subjecting the sample substance to these and other forms of stimulation for analysis purposes is usually referred to as spectroscopic examination or analysis. In FIG. 1 the substance 6 being examined is positioned in a separate container 7 which is located inside or outside the tube 3. It can also be confined, or positioned, in the tube 3 between the plates 1 and 2 as shown in FIG. 3, if desired.

FIG. 2 shows a somewhat similar construction to FIG. 1 but instead of using a tubular dielectric member it uses a dielectric rod 8. In this construction the substance to be examined is embedded in the rod 8 in granular or other form, as desired.

The construction shown in FIG. 3 is also similar to that shown in FIG. 1 but differs therefrom primarily because it has a dielectric rod 9 which extends through the plate 1a into the space defined by the dielectric tube 3a. The axial position of the rod 9 in this structure is preferably adjustable by sliding it through the plate 1a, and the rod 9 is used to vary the operating characteristics of the device including tuning the resonant cavity. Means can also be provided to retain the rod 9 in any desired position. The rod 9 can be constructed of a wide variety of materials including dielectric materials. As already noted, the substance 6 being examined is also shown confined only by the wall of the tube 3a and by the plates 1a and 2a and is not positioned in a separate container as in FIG. 1.

In the construction shown in FIG. 4 the cavity is defined by plates 1b and 2b and by the tube 3, and in this construction magnetic members 10 and 11 are provided to establish a magnetic field in the cavity. The magnetic members 10 and 11 can supply a DC magnetic field or an alternating field using modulating coils such as the coils 10a and 11a shown in FIG. 7. The magnetic modulation field in this case is introduced into the subject device without eddy current losses which normally occur with metal cavities. The location of the magnetic means is not critical to the operation and they can be located as shown or they can be located in other places as, for example, within or between the plates. If the field

produced by the magnetic means is modulated any suitable modulating frequency can be used.

If the subject resonant device is used for making spectroscopic examinations, it may be desirable to have the tube 3 or the rod 8 constructed of transparent or translucent dielectric material such as glass, quartz, plastic or like material. This enables the substance being examined to be exposed or stimulated by a greater number of energy forms such, for example, as visible and invisible light radiation, and this in turn substantially increases the information obtainable from such examinations. This is illustrated in FIG. 5 by the provision of light source 12 and lens 13 which are located and adjusted to focus light on the substance being examined. The substance in this case is shown for illustrative purposes as lump 14. In this construction therefore the lump 14 is exposed to microwave energy from a source such as the wave guide 4, a DC or fluctuating magnetic field produced by the magnetic means shown, and also to the light focused thereon from source 12. The light can be visible or invisible light.

FIG. 6 shows a modified form of transparent dielectric tube 15 in which the walls are constructed as one or more lens elements which serve the same purpose as lens 13 in FIG. 5 to focus light from an external source on a substance being examined. The substance in this case is also positioned inside the dielectric tube 15.

The changes that take place in substances under test due to exposure to the various stimulation forces including light energy can be noted by suitable detection means such as by an alternating current detection circuit which includes means for introducing and superimposing an AC signal into the region of the sample onto the microwave and other stimulation sources. Heretofore, resonant cavities have been enclosed on all sides by metal walls or the like which cannot be penetrated by certain kinds of energy such as modulating signals, high frequency magnetic fields, and light radiations, and this limited the possible ways of stimulating a sample and therefore also limited the usefulness of spectroscopy and other similar means of examining substances. These disadvantages are overcome by the present structure which has an open sided resonant cavity constructed in part by a dielectric member which can be made transparent so as to transmit other forms of stimulating energy.

One purpose of magnetic resonant spectroscopy is to determine the energy level splittings of materials. An energy level splitting is the difference between two or more energy levels, i.e.,  $E_2 - E_1 = h(f_2 - f_1)$  where  $E_1$  and  $E_2$  are different energy levels,  $h$  is a constant factor sometimes called Planck's constant, and  $(f_2 - f_1)$  is the frequency difference between particles at the different levels. If energy at the proper frequency is introduced into a substance some of the energy will be absorbed by the substance. The energy level differences or splittings which occur may depend upon the presence of a DC magnetic field and on its magnitude and direction of application. To observe energy level splittings, therefore, energy at frequency  $(f_2 - f_1)$  is introduced into the substance and the applied magnetic field is slowly varied until some energy absorption occurs. Since the amount of energy absorption is usually relatively small, microwave cavities such as described above are used to enhance the effect of the applied microwave field. In order to detect the energy absorption that takes place, an AC detection device is employed as aforesaid. The introduction of an AC signal in the region of the sample, which signal is superimposed on the microwave signal, is applied by means of a periodically time varying magnetic field. In the known cavity resonators, however, very high frequency modulated magnetic fields will not penetrate the metal cavity walls that contains the sample and therefore cannot be used effectively. This problem is overcome by the present cavity construction which has an open sided cavity in which the substance under examination is positioned in a dielectric

as distinguished from a metallic container. This therefore is an important advantage obtained by the subject device. By using a transparent dielectric tube the substance can also simultaneously be exposed to light radiations of any desired wave length.

FIG. 8 shows another modified form of the subject device wherein the device is made to operate as a maser. In this construction a rod 16 of ruby or some other suitable crystalline dielectric material extends between spaced conductive plates 17 and 18 which define the cavity. The microwave energy from the wave guide 19 produces a resonant condition or frequency in the dielectric rod 16. A second input wave guide 20 is positioned adjacent to the plate 17 and provides a second source of microwave energy which is the input signal and which is usually of considerably less magnitude than the signal produced by the pump 19. The input signal from the wave guide 20 produces a second different resonant condition in the ruby rod 16 so that two resonant conditions or modes exist simultaneously in the same cavity. The output from the maser is sensed in the wave guide 20 and is due to a change in the population distribution between energy levels which exist in the ruby rod 16. For example, considering that three distinct energy levels are possible in the rod 16, some of the electrons present at the first or lowest energy level will be stimulated by the microwave input from the pump source and will undergo a transition from the lowest energy level to the third or highest energy level thereby absorbing energy at frequency  $(f_3 - f_1)$ . Under suitable conditions the number of excited electrons in levels one and three may become equal leading to a situation in which more excited electrons reside in level three than two, or in two than one. This condition is known as population inversion. If a signal energy at the proper frequency  $(f_3 - f_2)$  or  $(f_2 - f_1)$  depending on the inversion, is now introduced the electrons in the inverted level will undergo a transition to a lower level emitting energy at the signal frequency.

The energy levels or states that the ruby particles possess when stimulated are discrete energy levels and the changes that take place also occur in discrete steps when the particles undergo a transition from one level to another. These changes are accompanied either by an absorption or an emission of photon of electromagnetic wave energy at a frequency determined by the difference in the frequencies of the different energy levels between which the changes occur. If, for example, a transition occurs from a low energy level to a higher energy level, energy absorption will take place, but if the transition is from a higher to a lower energy level then emission will take place. It must be remembered, however, that each change from a low level to a higher level is accompanied by a corresponding decrease in the population of the lower level after the stimulation is initiated. In the maser shown in FIG. 8 most of the energy absorption is produced by the energy pumped into the system through the pump wave guide 19. Therefore, in order for emission to occur the number of particles at the various levels, sometimes called the population ratio, must be modified or inverted so that there are more particles in the higher levels than in the lower levels otherwise useful energy will not be available at the appropriate transition frequency. The number of discrete energy levels can also be increased, if desired, by choice of different materials.

The theory of maser operation, including transitions between different energy levels to produce useful emission, is a well known phenomenon and as such is not part of the subject invention. However, the construction of a maser having an open sided resonant cavity as shown in FIG. 8 is new and represents an important application and construction of the subject invention.

In the maser described above the physical size of the resonator can be made relatively large even at relatively high frequencies which is an advantage not heretofore obtainable in masers using conventional resonant cavity

structures. It is also possible with a maser construction as shown and described to use an external energy source such as a source of light for added stimulation.

The dimensions and the specific configuration and resonant condition of all of the forms of the device shown and described can be varied as already noted and the dielectric member can also be chosen from a relatively wide range of materials and can have many sizes, shapes and dielectric constants. The geometry of the subject device also lends itself to many different experimental and other uses not heretofore possible with known cavity resonators some of which have been suggested. The subject devices can also be used to produce double resonant conditions using microwave and radio frequencies simultaneously, it can be used for radar applications, radio telescopic applications, spectroscopy, and for many other uses.

The subject device can be used for many different electron spin resonance experiments generally involving the interaction in a sample of microwave fields with one or more modulation fields. Typical electron spin resonance spectrometers employ alternating magnetic modulation fields to allow phase sensitive detection. In certain experiments it is also desirable to have optical energy interact with the sample. The introduction of optical energy or modulation signals to the sample is complicated in known resonant cavity structures by the presence of the cavity structure itself which supports the microwave fields. In the most commonly used microwave structure having a metallic wave guide cavity, eddy current losses substantially reduce the modulation field and this is undesirable and limits their usefulness. Attempts to overcome this problem with slits in the cavity wall, internal modulation coils and other means are also undesirable because they usually degrade the cavity Q and result in a complicated, bulky, and expensive construction. All of these problems are overcome by the present construction which is relatively simple to construct and use and which comprises two metal end plates separated by a dielectric rod or tube, means for coupling microwave energy into the structure through an iris in one of the end plates, and other means for introducing other forms of energy including magnetic energy and light energy.

What is claimed is:

1. A resonant cavity structure for use in electron paramagnetic resonance spectroscopy comprising a pair of spaced plate members constructed of electrical conducting material, a tubular member constructed of light conductive dielectric material extending across the space between said spaced plates at an intermediate position, a dielectric specimen to be analyzed positioned inside said tubular member, means including a waveguide coupled to the space defined between the spaced plates through an opening in one of the plates for introducing microwave energy into the space between said plates in the region of said dielectric member, and means for establishing a magnetic field in the space between said plate members and around said tubular member, said plates and said dielectric member defining an open sided resonant cavity capable of simultaneously supporting microwave energy at more than one kind of operating mode, the operating characteristics of which depend upon the size and shape of the aforesaid members.

2. A resonant cavity structure capable of simultaneously supporting more than one type of operating mode therein comprising a pair of spaced plate-like members constructed of electrical conductive material, a member constructed of dielectric material positioned extending across the space between said plates at an intermediate location, means including a waveguide coupled to the space defined between the plates through an opening in one of the plates for introducing microwave energy into the space between said plates and adjacent to said dielectric member, and other means including magnetic means having spaced pole pieces positioned on opposite sides of the space defined

between the plate-like members and on opposite sides of the dielectric member for establishing a substantially uninterrupted magnetic field between said plates and around said dielectric member.

3. The resonant cavity structure defined in claim 2 including means for time varying said magnetic field.

4. The resonant cavity structure defined in claim 2 wherein said dielectric member is tubular in shape and has opposite ends positioned respectively adjacent to said spaced plates.

5. The resonant cavity structure defined in claim 2 wherein said dielectric member is transparent.

6. The resonant cavity structure defined in claim 2 wherein said dielectric member is tubular in shape and is constructed of transparent material capable of focusing light falling thereon to a region defined therewithin.

7. The resonant cavity structure defined in claim 2 wherein said dielectric member is rod shaped.

8. A resonator device comprising a pair of spaced conductive plates, a dielectric member positioned extending between said plates, said plates and said dielectric member defining an open sided cavity capable of simultaneously supporting microwave energy at more than one type of operating mode therein, a waveguide mounted adjacent to one of said spaced plates, means including a hole formed in said one plate adjacent to said waveguide and adjacently to one end of said dielectric member, said hole establishing communication between the waveguide and the space defined between said plates and adjacent to said dielectric member for the introduction of microwave energy present in the waveguide into said space, means for establishing a substantially uninterrupted magnetic field between said spaced plates and around said dielectric member including a pair of spaced magnetic pole pieces positioned on opposite sides of the space defined between the plates and on opposite sides of the dielectric member, and means including a chamber in the dielectric member for containing a substance to be examined.

9. The resonator device defined in claim 8 including means for modulating said magnetic field.

10. The resonator defined in claim 8 wherein said dielectric member is tubular in shape and has light conducting properties, the chamber for positioning the substance to be analyzed being defined by the tubular shape of the dielectric member.

11. The resonator defined in claim 10 including a source of radiation energy, said substance to be analyzed being positioned to be exposed to the radiation energy source through the open space defined by the spaced conductive plates.

12. A resonator comprising a pair of spaced electrically conductive plates and a dielectric member extending therebetween, means including a waveguide positioned adjacent to one of the spaced plates and coupled to the space therebetween through an opening therein adjacent to one end of the dielectric member for introducing microwave energy into the space between said plates adjacent to said dielectric member, said plates and said dielectric member defining an open sided resonant cavity capable of simultaneously supporting microwave energy in more than one different kind of operating mode, and means for changing the resonant frequency of the cavity including a second member constructed of dielectric material extending through one of said conductive plates into the space between said plates, said second member extending through a hole in one of said plates and being movable through said hole relative to the resonant cavity, said second dielectric member being retained in a selectable adjustment position extending a predetermined distance into the space defined between the spaced conductive plates by frictional engagement thereof with the aforesaid dielectric member.

13. A maser comprising a resonant cavity including a pair of spaced plate-like members having electrical conducting properties, a dielectric member having suitable properties extending between said plate-like members, said

spaced plate-like member and said dielectric members defining an open sided cavity structure capable of simultaneously supporting microwave energy in at least two different kinds of modes, a first waveguide including a first source of microwave energy mounted adjacent to one of said plate-like members, means coupling said first waveguide to the space between said pair of spaced plate-like members for introducing microwave energy at a first predetermined resonant frequency into said cavity, a second waveguide including a second source of microwave energy mounted adjacent to the one of said plate-like members, means coupling said second waveguide to the space between said pair of spaced plate-like members for introducing microwave energy of another frequency into the cavity to produce resonance therein at a different frequency, and means for establishing a substantially uninterrupted magnetic field in said cavity.

14. The maser defined in claim 13 wherein said dielectric member extending between the plate-like members is constructed of ruby.

15. A maser comprising a pair of spaced plate-like members constructed of electrically conductive material, a crystalline member having dielectric properties extending between said plate-like members to define an open sided resonant cavity therewith, said cavity being capable of simultaneously supporting microwave energy in at least two different kinds of modes, a first waveguide including a first source of microwave energy mounted adjacent one of said plate-like members, means coupling said first waveguide to the space between said pair of spaced plate-like members for introducing microwave energy at a first frequency into said cavity, a second waveguide including a second source of microwave energy mounted adjacent to one of said plate-like members, means coupling said second waveguide to the space between said pair of spaced plate-like members for introducing into said cavity microwave energy of a different frequency, said first waveguide introducing microwave energy into the cavity to stimulate particles in the dielectric member to undergo transitions between first and second distinct energy levels, the second of said waveguides introducing microwave energy into the cavity to stimulate particles in the dielectric member to undergo transitions between one of the aforesaid energy levels and a third distinct energy level, and means for establishing a DC magnetic field in said cavity.

16. A maser device comprising a crystalline member having distinct quantum-transition energy levels denoted in increasing order of magnitude with transition frequency differences between the levels, a cavity resonator wherein said crystalline member is disposed for irradiation by wave energy, said cavity resonator being adapted to resonate simultaneously at each of said transition frequencies, said cavity resonator including an open sided cavity defined by a pair of spaced conductive plate members with the crystalline member extending therebetween, and means including separate microwave energy sources coupled to the cavity resonator through respective coupling orifices formed in the pair of spaced plate members at locations adjacent to the crystalline member for exciting said cavity resonator in such manner as to irradiate said crystalline member simultaneously at each of said transition frequencies to stimulate emission of radiation energy by said crystalline member.

17. The maser device defined in claim 16 including means for producing a substantially uninterrupted magnetic field in said cavity resonator.

18. A resonator device comprising a pair of spaced conductive plates, a dielectric member positioned extending between said plates, said dielectric member being tubular in shape and having light conducting properties, a waveguide mounted adjacent to one of said spaced plates, means communicating said waveguide with the space defined between said plates and adjacent to said dielectric member for the introduction of microwave energy into said space, means for establishing a magnetic field between

said spaced plates including a pair of spaced magnetic pole pieces positioned on opposite sides of the space defined between the plates and on opposite sides of the dielectric member, and means including a chamber formed by the dielectric member for positioning a substance to be examined, a source of radiation energy including a light source directed at said light conducting dielectric member and at the substance positioned therein to be analyzed.

References Cited

UNITED STATES PATENTS

|           |         |              |           |
|-----------|---------|--------------|-----------|
| 3,271,667 | 9/1966  | Czerlinsky   | 324—58    |
| 2,704,830 | 3/1955  | Rosencrans   | 333—83    |
| 2,838,736 | 6/1958  | Foster       | 333—83    |
| 2,813,251 | 11/1957 | Brown et al. | 324—58 XR |

|           |        |         |             |
|-----------|--------|---------|-------------|
| 3,165,705 | 1/1965 | Dicke   | 324—58.5 XR |
| 3,267,360 | 8/1966 | Dehmelt | 324—5       |

OTHER REFERENCES

- Thorp et al., Journal of Electrons and Control, vol. X, No. 1, January 1961, pp. 13—24.  
 Hakki et al., IRE Transactions on Microwave Theory and Techniques, July 1960, pp. 402—410.  
 Okaya et al., Proceedings of the IRE, vol. 50, October 1962, pp. 2086—2092.

RUDOLPH V. ROLINEC, *Primary Examiner.*

P. F. WILLE, *Assistant Examiner.*

U.S. Cl. X.R.

330—4; 333—83