

[54] **MULTIMODE MICROWAVE CAVITIES FOR MICROWAVE HEATING SYSTEMS**

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[51] Int. Cl. **H05b 9/06, H01p 7/06**

[58] Field of Search **333/83 R; 219/10.55**

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[57] **ABSTRACT**

The present invention pertains to a new, smaller multimode cavity which may be used as a threadline heater fed by a variety of coupling structures or it may be used to advantage as a means for coupling energy to a larger cavity. The cavity consists of four side walls and two end walls with a number of spaced metallic vanes placed within the cavity transverse to the desired electric field forming a multimode cavity having a number of small resonators which may be tuned in any conventional manner such as by simple bolt.

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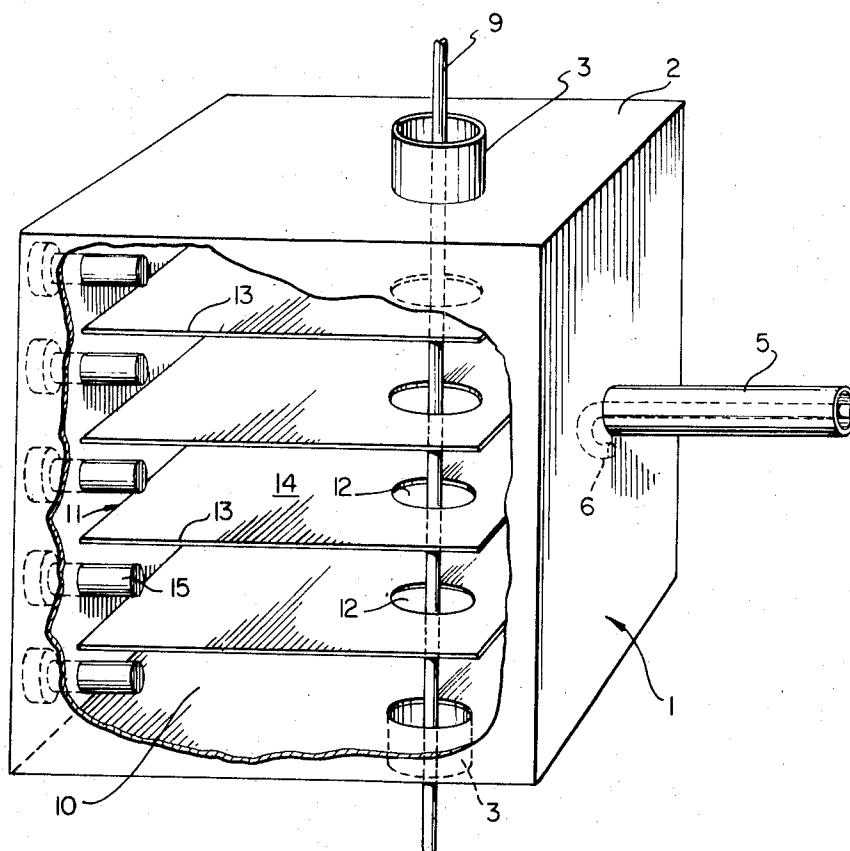
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5 Claims, 8 Drawing Figures



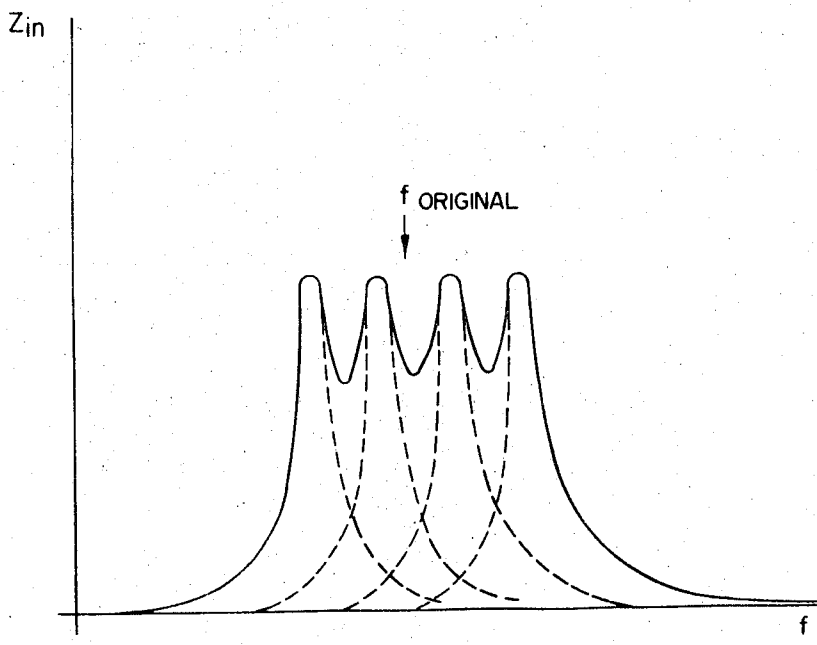
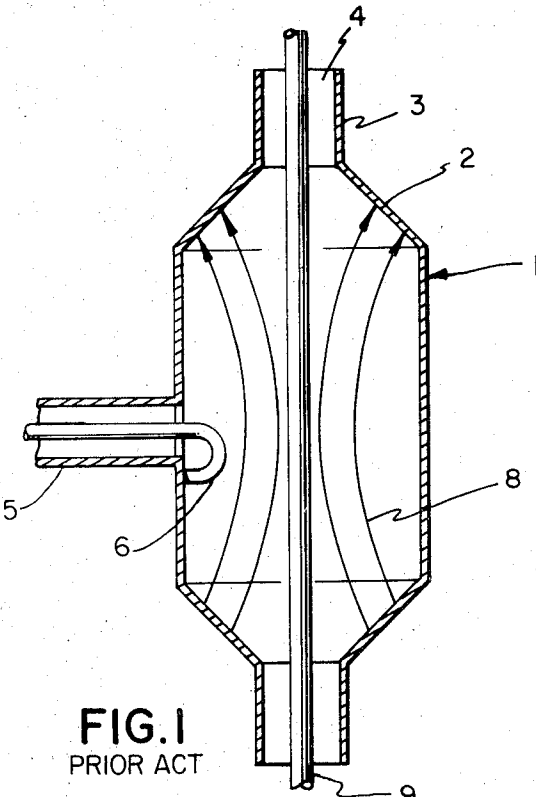


FIG. 2

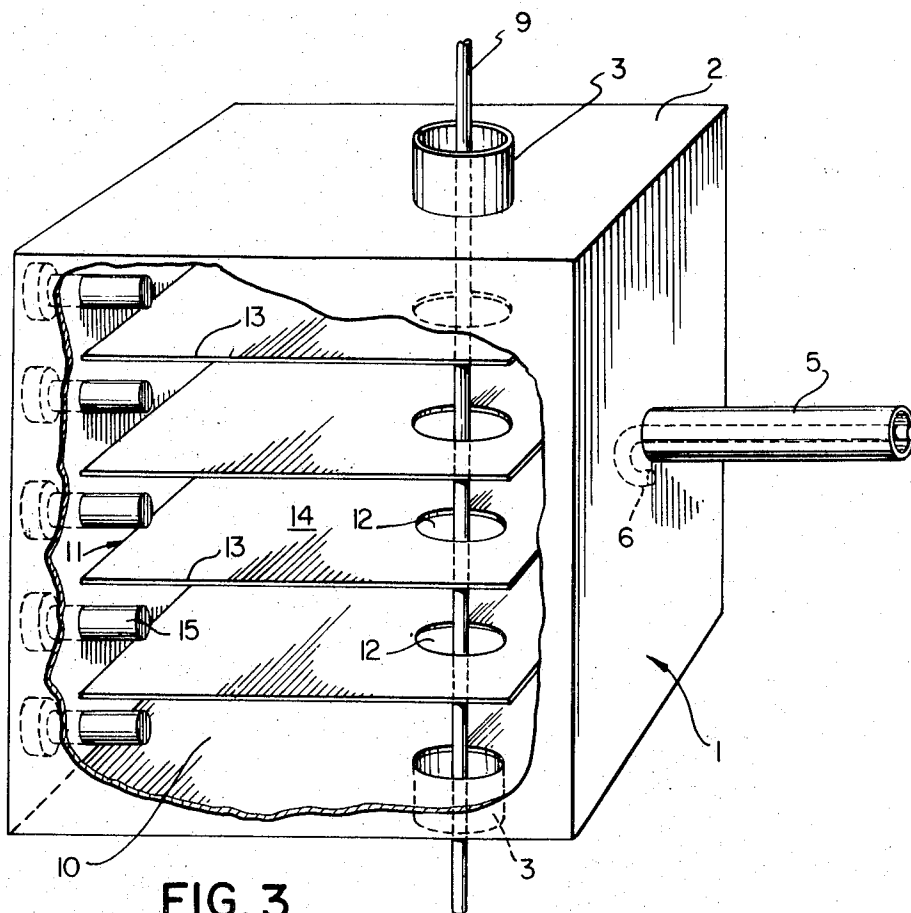


FIG. 3.

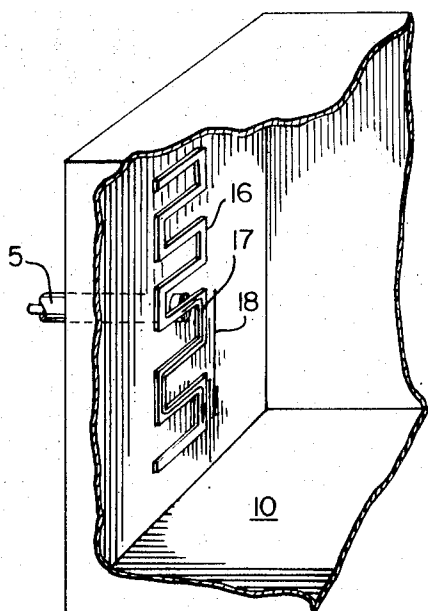


FIG. 4

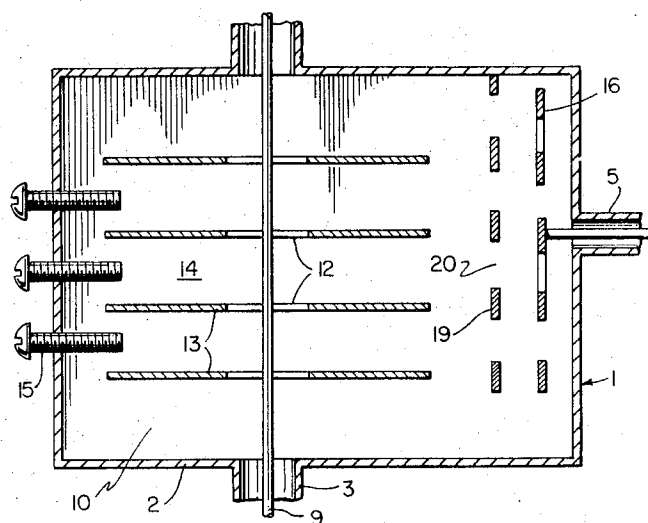


FIG. 5.

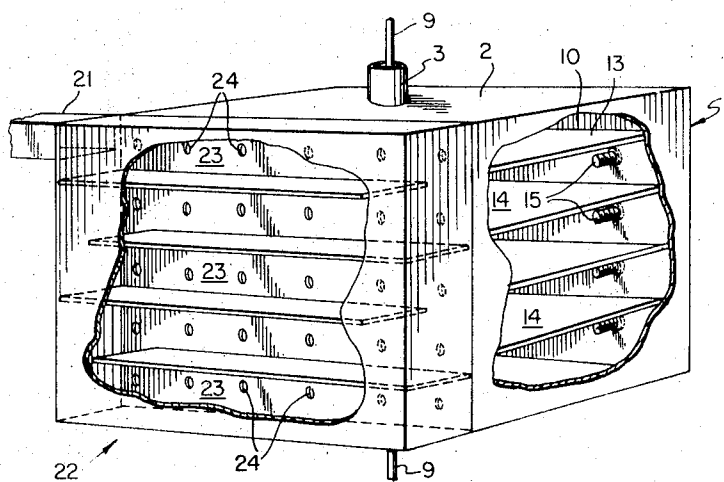
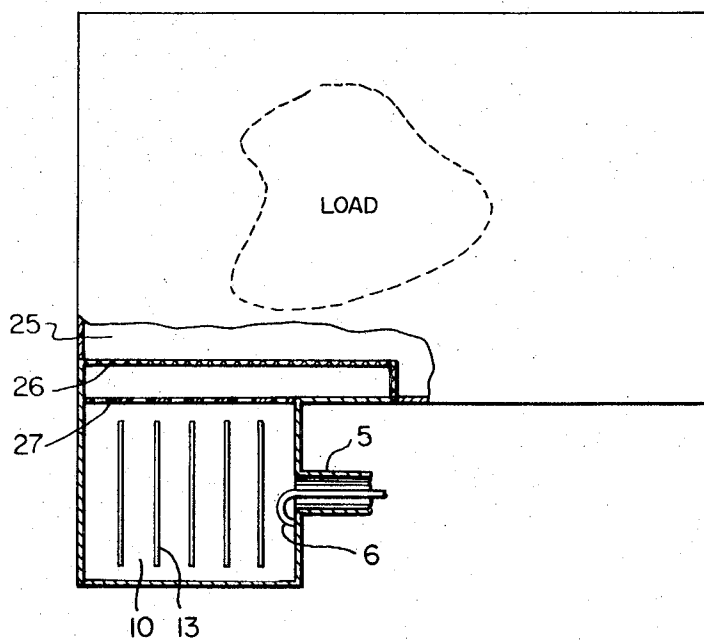
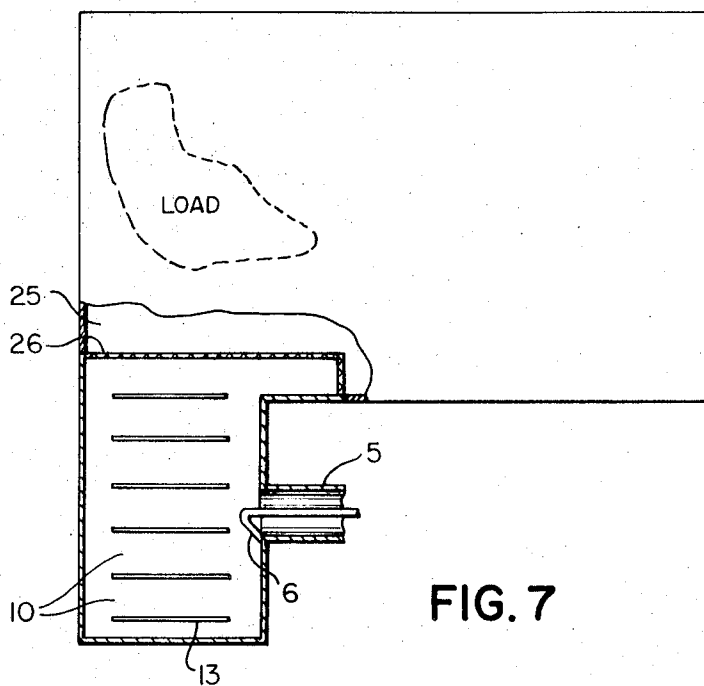


FIG. 6.



MULTIMODE MICROWAVE CAVITIES FOR MICROWAVE HEATING SYSTEMS

This invention relates to microwave heating system and more particularly to small multimode microwave applicators for use primarily in threadline type applications such as the heating of fabric filaments, fiberglass rods, yarns, sausages etc., and secondly as sub-structures in larger cavities.

Microwave systems for such use generally consist of a magnetron producing microwave power, a transmission line or waveguide to carry the power, a coupling structure to apply power to a cavity or applicator and lastly the load to be heated.

The wave in the transmission line excites electric and magnetic fields in the coupling structure, which in turn excites standing wave (resonant) fields in the cavity. The load absorbs power from these fields, and the character of the standing wave fields depends strongly on the size, shape and placement of the load.

Microwave threadline driers normally use a single mode, which is tuned to the frequency of the applied power usually in the ISM (Industrial, Scientific and Medical) bands, 915±25MHz and 2450±50 MHz. A filament or such is threaded within an outer metallic wall and is heated or otherwise processed. The electric vectors are almost always parallel to the filament since this gives maximum heating. These electric and magnetic fields are excited in the cavity by an inlet transmission structure and a coupling structure such as a simple loop.

Each mode or spatial orientation of the fields has a specific preferred frequency. At other frequencies this mode stores energy badly. It is common for the usable frequency range of the applicator to be much less than the ISM bands and the tuning of the cavity to a particular magnetron or other power source becomes a very tedious and expensive task. If the dielectric properties or the size of the filament change, the cavity becomes detuned, often to a frequency outside of the ISM bands. The amount of detuning is proportional to the ratio of load to cavity volume and increases with electric field strength. However, it is desirable to maintain high field strength to produce maximum energy absorption.

The techniques used to overcome this problem have detuned the magnetron from its preferred frequency to one which is optimized for the magnetron-cavity-filament system as a whole. It is the purpose of this invention to introduce a type of cavity which places less stringent requirements on the magnetron power source and which gives less chance of operating a high power system in one of the communication bands.

For examples of the prior art of threadline microwave power applicators see U.S. Pat. No. 2,364,526 issued Dec. 5, 1944, to C. W. Hansell and the article "A Microwave Apparatus for Rapid Heating of Threadlines" by Huang, in the Journal of Microwave Power 4 (4) p. 288, (December 1969).

On the other hand conventional microwave ovens use multimode cavities, which are large enclosures in which several orientations of the fields in the inside give rise to roughly the same frequency. This means that if the load detunes one mode to a frequency which is not within the magnetron's band, another one is available to accommodate the new loading condition. It is also true that the absorption of energy in the load broadens each mode so that the whole band is more or

less acceptable to any replacement magnetron. See "Some Factors Affecting Energy Conversion in a Multimode Cavity", by James, Tinga and Voss, Journal of Microwave Power 1 p. 97 (1966).

These structures are large and only one third of the modes have electric vectors which are parallel to a chosen filament direction. The size reduces the sensitivity to detuning, but it is primarily used as a technique for obtaining large numbers of modes. The patterns of fields in a mode have zero tangential electric field strength at the walls and in addition have nulls in other planes through the cavity. The spacing between these null planes is about ½ wavelength except in the special case when the electric vectors are perpendicular to the metallic walls.

In present multimode systems, where coupling structures such as loops, horns, straps or probes are used, the presence of standing wave fields in the vicinity of a coupling structure causes voltages to be induced in it, and since the transmission line is connected to it, a wave may be returned to the magnetron. This is reflected power, which causes problems of back-bombardment of the cathode by electrons, reduced power output and efficiency, and decreases tube life. Present coupling structures in use are all susceptible to such large power reflections back to the source, i.e. the (magnetron) generator and have necessitated development of very rugged magnetrons or other stringent measures to circumvent the problem; e.g. using isolators, a type of power absorbing one-way flow structure within the transmission lines.

It is therefore an object of the present invention to provide a new, smaller, multimode microwave cavity.

Another object of the present invention is to provide a new multimode applicator for threadline heating applications.

Still another object of the present invention is to provide a small multimode applicator which is capable of supplying a mode at the frequency of the magnetron even when loaded with varying loads and simultaneously producing high field strength in a controlled direction.

Still another object of the invention is to provide a multimode cavity with coupling structure which reduce power reflections to the source.

These and other objects are achieved by a small cavity having four side walls and two end walls, and a number of spaced metallic vanes placed within the cavity transverse to the desired electric field thus forming a multimode cavity having a number of small resonators which may be turned in any conventional manner such as by simple bolts. When used for threadline heating applications, openings are provided in the end walls as well as through the vanes, thus allowing a rod or filament, etc., load to move through the cavity. When used as a subsystem openings are provided in one of the walls to allow power to flow from the small multimode cavity to a larger cavity. In addition, any conventional coupling structure, such as a loop, probe, etc., may be used to couple power to the cavity, however in the preferred embodiment, a slow wave coupling structure which may form an integral part of the cavity structure, is used.

In the drawings which illustrate embodiments of the invention,

FIG. 1 is a schematic view of a conventional threadline applicator,

FIG. 2 is a graph showing the effect caused by the coupling of several resonators,

FIG. 3 is an isometric view of an embodiment of the invention as used for threadline heating.

FIG. 4 is an isometric view of one form of a transmission line slow wave coupling structure,

FIG. 5 is a cross sectional view of a threadline embodiment with a slow wave coupling structure,

FIG. 6 is an isometric view of a waveguide slow-wave coupling device as an integral part of the cavity,

FIG. 7 is a cross sectional view of an embodiment of the invention as a subsystem for a larger cavity.

FIG. 8 is a cross sectional view still another embodiment of the invention as a subsystem for a larger cavity.

Conventional threadline driers, an example of which is shown in FIG. 1, use a single mode usually in the ISM bands. The device consists of outer metallic walls 1, end walls 2 and a collar 3 forming an opening 4 at each end of the cavity. Electric and magnetic fields are excited in the cavity by an inlet transmission structure 5 and a coupling structure 6 in such a manner that the electric vectors 8 are almost always parallel to a threadline type load, filament 9, since this gives maximum heating within the load.

In reducing the size of multimode structures to a size desired for threadline type applications while retaining the option of operating the source in one of several modes, it has been determined that reducing the size reduces the Q of the cavity, broadening each mode for a given load, and causes more overlapping of modes. A further fortunate fact is that when several resonators all operating at the same frequency are coupled together, the modes of the resulting system are spread in frequency. The amount of the spreading is proportional to the amount of coupling of stored energy between resonators. In FIG. 2 this effect is shown for a system of four resonators. The vertical axis represents the input impedance seen at the coupling structure. The individual peaks represent modes and the dotted line shows the overall input impedance. f_0 is the resonant frequency of the individual resonators.

In FIG. 3 a structure is shown which meets the above requirements. Metallic plates 13 have been introduced into a small cavity 10 transverse to the desired electric field. Each of these plates 13 provides a plane for charges and currents to reside on, eliminating the need for half wavelength spacing between nulls. The spaces 14 between pairs of plates 13 may be alternately viewed as waveguide resonators operating in a $TE_{n,0,m}$ mode. The resonators are individually tuned to one or more of the ISM frequencies and are coupled at the ends 11 and the holes 12 in the plates. The load 9 is placed parallel to the electric field for maximum power absorption as in FIG. 3 or perpendicular to it if minimum absorption is desired. Each resonator may be tuned by a simple bolt 15, preferably smoothed and plated to lower metal losses.

This structure permits adjustment of the bandwidth by simply increasing or decreasing coupling at either the ends or the holes. Stagger tuning is also possible. The field strength may be adjusted in the case of very heavy loads such as sausages by placing the load in a region of low field strength, as at the ends.

The reflection from the cavity is also very dependant on the coupling structure chosen which in FIG. 3 is shown as a simple loop 6.

FIG. 4 shows the basic structure of a slow wave coupling device 16 which induces standing fields in a cavity 10. The transmission structure 5 is shown as a coaxial transmission line. The actual path of the wave 17 is long compared to the net forward travel 18 and the variations in the induced fields. The spacing between straight sections gives control over preferred modes of wave launching. For example, if the conductor is made 1 cm wide, 1 cm between adjacent 13 cm long parts of the conductor and $\frac{1}{2}$ cm above the ground plane, or wall of the cavity, very broad modes are observed at both 915 and 2,450 MHz. The length may be varied indepently of these frequency considerations. Many other combinations give excellent coupling at one or more of the ISM bands and larger structures are less likely to suffer arcing problems. The slow wave structure 16 is fed from the centre and its characteristic impedance is adjusted to twice that of the transmission structure, since two sections are effectively connected in parallel.

However the slow wave structure may also be fed from either end.

The preferred threadline applicator is again shown in FIG. 5, however it is combined with a shielded slow wave coupling structure with coupling device 16 centrally connected to transmission line 5. A shield 19, which consists of a metallic plate with openings 20 to permit coupling from the structure to the resonators, has been added to permit reduced mutual reactance with the fields in the cavity. Charges and currents on the shield form locations where the cavity fields may terminate, and only the remaining fields are present on the coupling structure. This may be necessary in the case of small and/or lightly loaded cavities. This coupling structure has been found to markedly decrease problems of reflections due to residual fluctuations in loading.

Another form of coupling structure is shown in FIG. 6 as an integral part of the cavity 10. Both the coaxial and waveguide transmission coupling structures may be manufactured as an integral part of the cavity structure or they may be detachably mounted on the cavity.

Many sources are designed to feed a waveguide transmission line 21. Instead of introducing a waveguide to coaxial transmission line transition, a waveguide slow wave structure 22 may be used. The wave follows a sinuous path in the chamber 23. Its energy leaks into the cavity 10 through coupling holes or slots 24. The path is inside sections of rectangular waveguide whose phase velocity may be kept low by those skilled in the art. Multipath and other slow wave structures will perform the same function.

In addition to the use of the small multimode cavity in threadline heating applications, it may be used for the production of free chemical radicals in the gaseous phase from plasmas contained in tubes by inserting the tube into the cavity, as above, through its openings at either end. For example, with the cavity operating in the 915 $\pm$ 25 MHz band at 10 watts, the structure is capable of igniting and sustaining the argon-mercury arc of a common fluorescent tube.

Yet other applications of the small multimode cavity are shown in FIGS. 7 and 8.

In FIG. 7 the end of the vaned cavity 10 has been used and the energy is coupled into a larger cavity 25, the design of which is well known to those skilled in the art. The modes of the two cavities combine to give a multimode microwave oven with small size and hitherto unattainable mode density. A dielectric cover 26 isolates the two cavities for sanitation. The coupling between cavities can take many forms. In addition to the example of FIG. 7 it is possible to couple at the sides, through a slot array as shown in FIG. 8. The vaned cavity 10 then forms a slow wave coupler, with attendant advantages of lower reflected power and better energy distribution.

We claim:

1. A multimode microwave applicator comprising:
 - a cavity having two pairs of parallel side walls and parallel end walls;
 - a coupling structure connected to a transmission line and mounted through a first one of said walls for providing power to said cavity;
 - a number of spaced metallic vanes mounted within the cavity transverse to the electric field, forming resonators within said cavity; and
 - a second one of said walls consisting of a slotted array coupled to a further cavity.
2. A multimode microwave applicator comprising:
 - a cavity having two pairs of parallel side walls and parallel end walls; and
 - a coupling structure to provide power to the cavity through one of said walls, said coupling structure including a square wave shaped conductor mounted within the cavity in spaced relationship to said one wall and connected to a coaxial transmission line to conduct power to said conductor, and a perforated metallic plate mounted within the cavity in spaced relationship to said conductor; and
 - a number of spaced metallic vanes mounted within the cavity transverse to the electric field forming

resonators within said cavity.

3. A multimode microwave applicator comprising:
 - a cavity having two pairs of parallel side walls and parallel end walls;
 - a coupling structure adapted to be connected to a transmission line, said coupling structure including a chamber mounted on one wall of said cavity with metallic vanes mounted within the chamber to form reversing sections of rectangular waveguide and openings in the walls of said waveguide to couple power to said cavity; and
 - a number of spaced metallic vanes mounted within the cavity transverse to the electric field forming resonators within said cavity.
4. A multimode microwave applicator comprising:
 - a cavity having two pairs of parallel side walls and parallel end walls; and
 - a coupling structure to provide power to the cavity through one of said walls, said coupling structure including a square wave shaped conductor mounted within the cavity in spaced relationship to said one wall and connected to a coaxial transmission line to conduct power to said conductor, and a perforated metallic plate mounted within the cavity in spaced relationship to said conductor.
5. A multimode microwave applicator comprising:
 - a cavity having two pairs of parallel side walls and parallel end walls; and
 - a coupling structure adapted to be connected to a transmission line, said coupling structure having a chamber mounted on one wall of said cavity with metallic vanes mounted within the chamber to form reversing sections of rectangular waveguide and openings in the walls of said waveguide to couple power to said cavity.

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