United States Patent

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[54] **MICROWAVE APPLICATOR EMPLOYING FLAT MULTIMODE CAVITY FOR TREATING WEBS**
8 Claims, 7 Drawing Figs.

[52] **U.S. Cl.** **219/10.55,** 219/10.61
[51] **Int. Cl.** **H05b 9/06,** H05b 5/00
[50] **Field of Search** 219/10.55, 10.61

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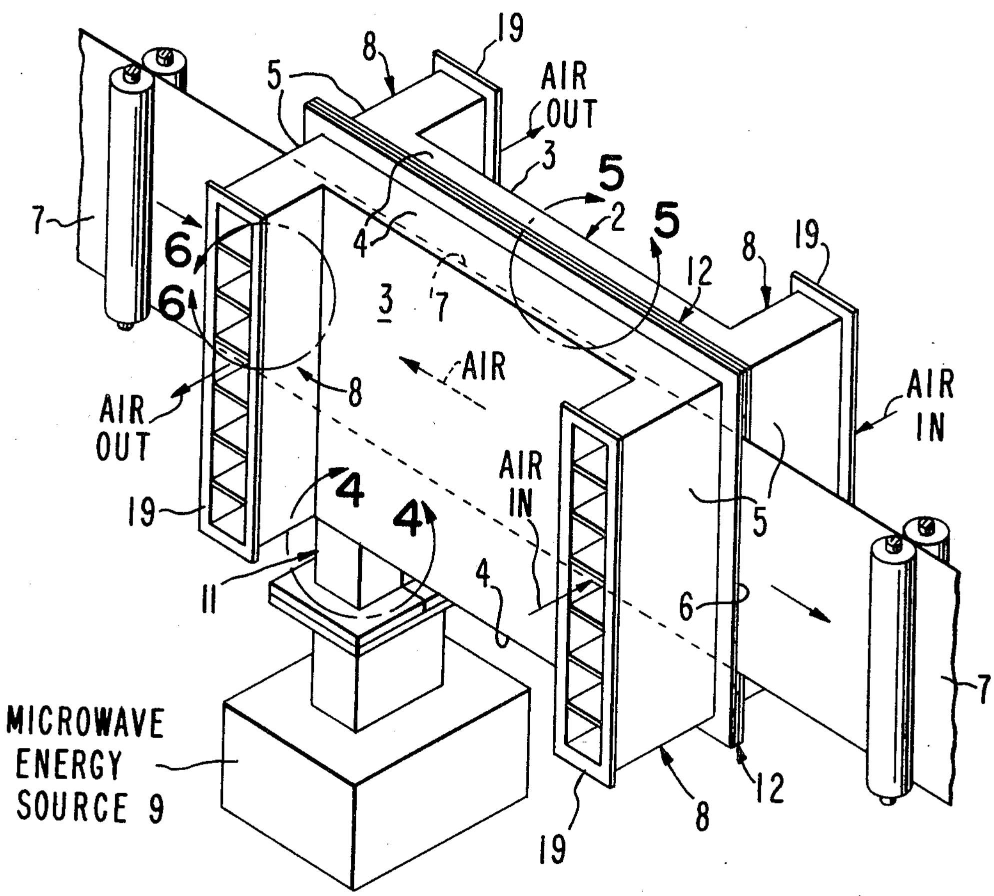
ABSTRACT: A microwave applicator is disclosed. The applicator includes a flat multimode cavity having openings on opposite sides thereof for passing therethrough a web of material to be treated with microwave energy. The cavity is both designed and fed so as to be excited at its operating frequency only in those $TE_{l,m,n}$ and $TM_{l,m,n}$ classes of modes such that the value of l is limited to 1 and m or n or both have a value greater than zero (preferably both m and n have a range of values which includes 10) and such that the E-vector of the microwave energy lies generally in the plane of the treatment zone and has maximum intensity in the treatment zone. The flat multimode cavity resonator is fabricated in two half sections an upper half and a lower half which are joined together at their edges. A mode-damping means is provided for attenuating a certain undesired class of modes that could otherwise be supported within the cavity. Air ducts are provided at opposite ends of the resonator for directing air either parallel or antiparallel to the direction of movement of the web to be treated.



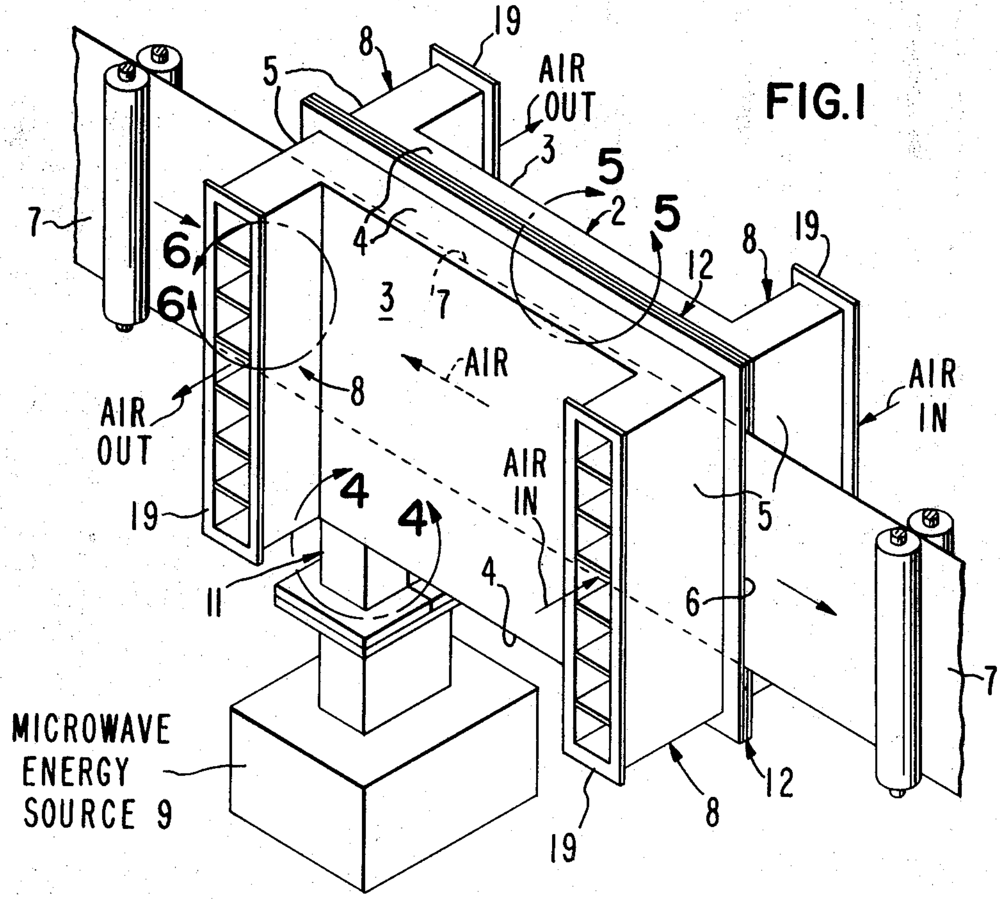


FIG.1

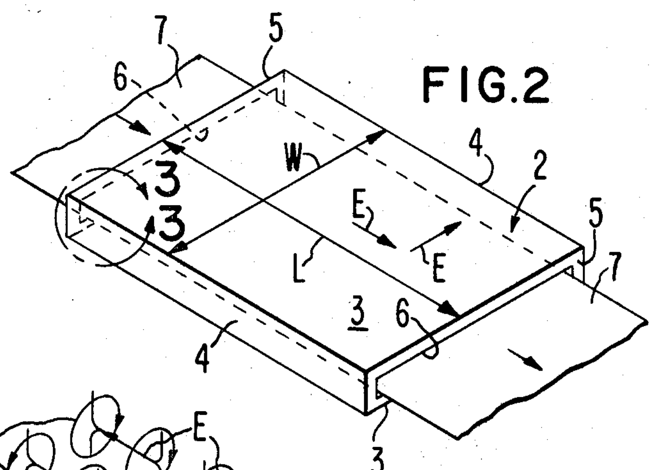
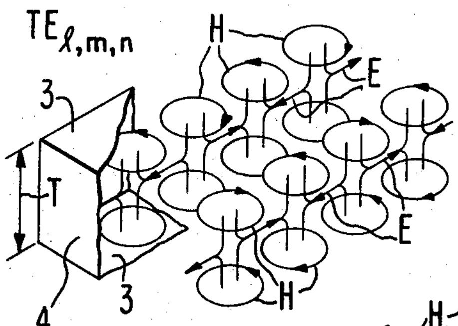


FIG.2

FIG.3A

$TE_{\ell,m,n}$



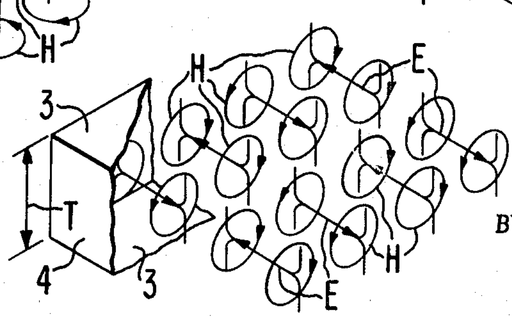


FIG.3B

$TM_{\ell,m,n}$

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FIG. 6

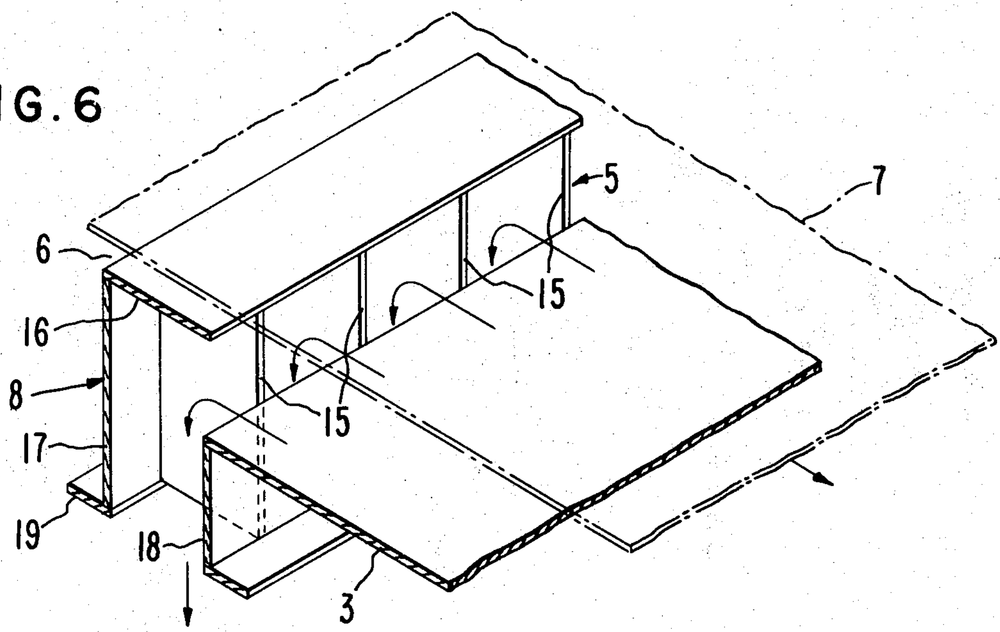


FIG.5

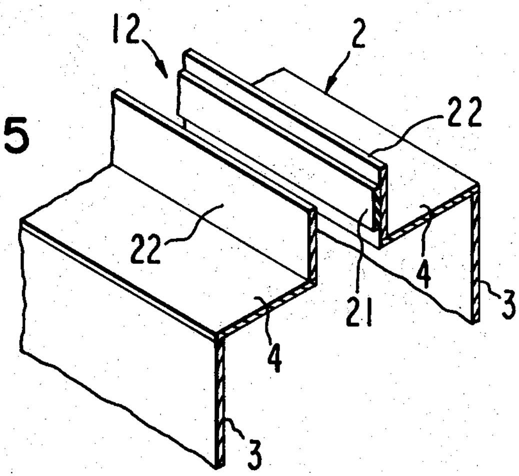
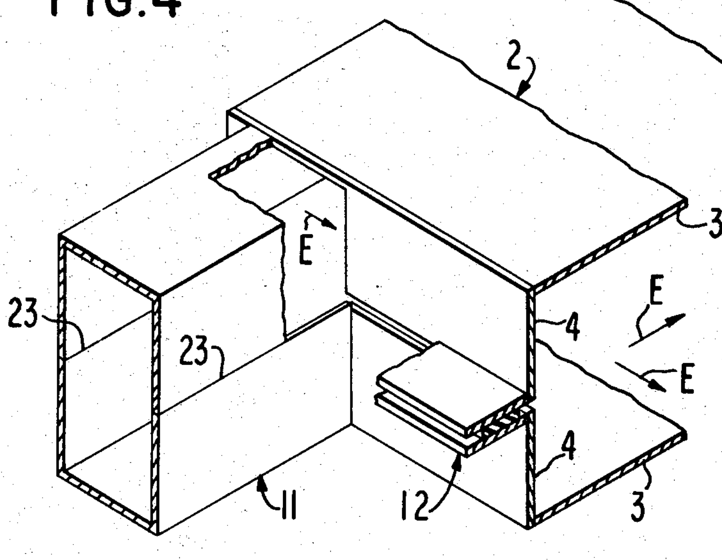


FIG.4



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MICROWAVE APPLICATOR EMPLOYING FLAT MULTIMODE CAVITY FOR TREATING WEBS

DESCRIPTION OF THE PRIOR ART

Heretofore, multimode cavity resonators, excited such that the E-vector is parallel to the plane of a web of material to be treated, have been employed for treating webs of dielectric material. One such prior art applicator is disclosed in U.S. Pat. No. 2,650,291 issued Aug. 25, 1953. One of the problems with this prior art applicator is that the cavity is relatively deep in the direction perpendicular to the plane of the web such that the cavity can support certain undersired modes of oscillation with the electric vector perpendicular to the plane of the web at the plane of the web. These modes, with the E-vector perpendicular to the web, are generally undesired since they contribute very little to heating of the material being treated and being therefore lightly loaded can cause arcing and breakdown of the air dielectric in the cavity. Such modes also cause excessive leakage of microwave energy through the openings provided for the web material.

Others have built waveguide-type applicators wherein the waveguide was formed in a serpentine manner, thereby producing a relatively flat applicator. The waveguide was sometimes formed in two half sections and hinged at one side of the web of material to be treated to facilitate threading of the web into the applicator structure and to facilitate cleaning and maintenance of the structure. However, one problem with the prior waveguide applicator is that the serpentine arrangement of the waveguide makes it difficult to duct air through the applicator and the applicator is generally a relatively complex structure. Due to their structural complexity waveguide applicators are more costly to fabricate, tend to be physically larger and heavier and are inherently more lossy and thus less efficient than cavity-type applicators. They are also more difficult to ventilate and clean and have a tendency to collect undesired matter in their physically intricate interior. Finally, the space which is allowed for the passing of material to be treated is quite critical for efficient transfer of microwave energy to the material, thus requiring careful control over the dimensions and motion of such material. Such a waveguide applicator is disclosed in U.S. Pat. No. 2,560,903 issued Jul. 17, 1951.

SUMMARY OF THE PRESENT INVENTION

The principle object of the present invention is the provision of an improved microwave applicator.

One feature of the present invention is the provision of a relatively flat applicator cavity resonator which supports classes of resonant modes such that the electric vector of the field midway between the broad walls of the cavity is parallel to the plane of the broad walls of the cavity, such cavity having a height in a direction perpendicular to the broad walls, which is less than a wavelength at the operating frequency, whereby certain undesired classes of modes (specifically $l>2$) modes having electric field vectors perpendicular to the broad walls midway between the broad walls of the cavity are not supported. Another feature of the present invention is the same as the preceding feature wherein the broad walls are dimensioned to have sufficient length and width to support the $TE_{l,m,n}$ and $TM_{l,m,n}$ modes at the frequency of operation, where l is 1 and at least m or n is greater than **10**, whereby mode stirring is readily achieved by frequency modulating the exciting microwave energy applied to the cavity.

Another feature of the present invention is the same as any one or more of the preceding features wherein a rectangular waveguide is coupled to the cavity for exciting the cavity with microwave energy, the waveguide being oriented relative to the cavity such that the broad walls of the rectangular waveguide are perpendicular to the planes of the broad walls of the cavity, whereby the desired classes of modes of oscillation are excited to the exclusion of other possible modes.

Another feature of the present invention is the same as any one or more of the preceding features wherein the cavity resonator comprises two similar half resonator portions joined together along a joint formed in the narrow sidewalls and including a lossy, mode-damping material disposed in the joint for suppressing certain undesired modes of oscillation having their electric field vectors perpendicular to the broad walls of the cavity (specifically, the $TE_{o,m,n}$ class of modes).

Another feature of the present invention is the same as any one or more of the preceding features including the provision of air ducts disposed at the narrow end walls of the cavity for directing air or other gasses through the cavity in a direction parallel or antiparallel to the direction of movement of the material being treated within the cavity.

Other features and advantages of the present invention will become apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic, perspective, line diagram, partly in block diagram form, depicting a microwave applicator incorporating features of the present invention;

FIG. **2** is a simplified schematic line diagram of a flat multimode cavity incorporating features of the present invention;

FIGS. **3A** and **3B** depict the desired mode patterns to be excited in the cavity of FIG. **2** the mode patterns being shown for a portion of the structure of FIG. **2** delineated by line **3–3**;

FIG. **4** is a schematic line diagram of a portion of the structure of FIG. **1** delineated by line **4–4**;

FIG. **5** is a fragmentary perspective view of a portion of the structure of FIG. **1** delineated by line **5–5**; and

FIG. **6** is a fragmentary perspective view, partly in section, of a portion of the structure of FIG. **1** delineated by line **6–6**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. **1** there is shown the microwave applicator of the present invention. The applicator includes a flat multimode rectangular cavity resonator **2** defining a relatively thin rectangular treatment zone centrally disposed within the cavity **2** in a plane midway between the broad walls **3** of the resonator. The resonator **2** includes opposite pairs of narrow sidewalls **4** and **5**. Narrow sidewalls **5**, at the ends of the resonator **2**, include elongated apertures **6** for the passage of a web **7** of dielectric material to be treated with microwave energy within the cavity **2**. The applicator is particularly useful for heating and drying flat webs, sheets, or films of material, such as drying a polyvinylidene coating of a thickness of between 0.1 to 1.0 mils on a 1 to 5 mil thick 3 to 4 foot wide continuously moving paper web, such web moving at speeds between 200 and 600 feet per minute.

Systems of air ducts **8**, more fully described below with regard to FIG. **6**, are provided in the end walls **5** of the resonator **2** for directing streams of air adjacent the moving web **7**. The direction of flow is antiparallel (i.e., parallel and counter) to the direction of movement of the web and the stream is on both sides of the web **7** through the treatment zone.

A source of microwave energy **9**, such as a magnetron oscillator, is coupled to the cavity **2** via a rectangular waveguide **11**. The waveguide **11** is arranged such that the broad walls of the waveguide **11** are perpendicular to the broad walls **3** of the cavity, such that classes of modes of oscillation are excited within the cavity having their electric vectors parallel to the broad walls **3** of the cavity **2** at the plane of the web **7**. In this manner, the strong electric field vector is disposed in the plane of the web **7** within the centrally disposed treatment zone of the resonator **2**. When the electric vector is in the plane of the web **7**, the most effective heating effect is obtained. The cavity modes, methods of excitation, and the dimensions of the cavity are more fully described below with regard to FIGS. **2—4**.

The cavity **2** is formed in two similar half sections which are fitted together along joint **12** in the narrow sidewalls **4** on opposite sides of the web **7**. The nature of the joint **12** is more fully described below with regard to FIG. 5. The two halves of the cavity resonator 2 are held together by suitable fasteners such as screws, clamps or the like, not shown.

Referring now to FIGS. 2—4, the desired classes of modes of oscillation within the cavity are described together with dimensional considerations to obtain the desired classes of modes. The desired classes of modes of oscillation within the cavity 2 are those in which the electric field vectors E lie in a plane parallel to the broad walls 3 of the cavity 2 at the plane of the web 7. In addition, the electric vectors should have their maximum intensity at a point midway in the thickness T of the cavity, where the thickness T is the spacing between the broad walls 3. The desired $TE_{l,m,n}$ and $TM_{l,m,n}$ modes are generally depicted in FIGS. 3A and 3B, respectively.

The cavity 2 preferably has a length L and a width W sufficiently great such that the cavity will support the aforedescribed modes of oscillation where either m or n or both are greater than 10, and the cavity should have a thickness T such that l is no greater than 1. This means that the thickness T of the cavity 2 must be between one half and one wavelength.

If the thickness T is less than a half wavelength the desired classes of modes cannot be supported within the cavity and if the thickness T is greater than one wavelength the cavity can support certain undesired classes of modes of oscillation, wherein the electric vector E is perpendicular to the broad walls. Such modes are particularly troublesome since they lead to voltage breakdown at high power levels resulting in undesired arcing and excessive leakage of microwave energy from the apertures 6. Furthermore, such modes contribute very little to heating since their electric vectors are perpendicular to the plane of the thin web 7 being treated.

By making the length L and width W dimensions of the cavity 2 sufficiently large such that the range of the m or n designators of the excited modes is in excess of 10 it is assured that the various resonant frequencies of the excited modes within the cavity are closely spaced in frequency. This has the advantage of enabling mode starring to be more readily accomplished.

Referring now to FIG. 4, there is shown the waveguide coupling arrangement for exciting the desired $TE_{l,m,n}$ or $TM_{l,m,n}$ modes within the resonator 2. The desired modes have strong electric field vectors E in the plane midway between the broad walls 3 with the E vectors being parallel to the broad walls. These desired classes of modes are excited by the dominant modes in the input waveguide 11 when the waveguide is coupled near a corner of the cavity 2 and when the waveguide 11 is arranged with the broad walls of the guide perpendicular to the broad walls 3 of the cavity 2.

The waveguide 11 is split to form a joint 23, such that the waveguide is divided into two mating portions, one portion being fixedly secured as by welding to each of the separate half sections of the cavity 2. Very little leakage of microwave energy through the joint 23 is obtained because the dominant mode of the waveguide 11 has essentially no coupling to the longitudinal joint 23 located in the center of the broad walls.

Although the resonator 2 is specifically designed and fed so that undesired classes of modes are neither supported nor excited, it is impossible to avoid supporting and weakly exciting at least one undesired class of modes, namely, the $TE_{o,m,n}$ class. This class of modes is typical of the undesired classes of modes, wherein the electric vector is perpendicular to the broad walls 3 and these modes are, of course, the undesired modes since they contribute very little to the heating of the web 7 and since they can cause arcing and breakdown within the cavity 2. Thus, according to a teaching of this invention, a mode-damping means is included in the cavity 2 which preferentially couples to these undesired modes and suppresses them.

Referring now to FIG. 5, there is shown a preferred mode-damping structure for suppressing undesired classes of modes of resonance within the cavity 2. More specifically, the joint 12 between the mating lip portions 22 of the narrow sidewalls 4 include a lossy mode-damping element 21. In FIG. 5, the lip portions 22 are shown separated for ease of explanation. The lossy mode-damping element 21 may comprise, for example, a sheet of rubber loaded with lossy powders, such as powders of iron, carbon or ferrites. The mode-damping element 21 serves to heavily attenuate any mode within the cavity 2 having currents in the sidewall 4 which tend to flow across the joint 12.

Referring now to FIG. 6, there is shown the system of air ducts 8 for ducting air through the treatment zone in a direction counter to the direction of movement of the web 7. The end walls 5 of the resonator 2 are formed by a plurality of conductive septums 15 as of aluminum. The planes of the septums 15 are perpendicular to the plane of the broad walls 3 and the inner side edges of the septums 15 define the conductive path for the end wall portions 5 of the resonator 2. The septums 15 are closed off at their inner end by means of a conductive plate 16 which also defines the marginal lip of the opening 6 in the end wall 5, which opening permits the web 7 to pass through the cavity 2. A plate 17, as of aluminum, closes off the outside side edges of the septums 15 and a similar plate 18 closes off the inner side edges of the septums 15, externally of the cavity 2, to define a plurality of air passageways through the end wall 5 of the resonator 2. The inside cross-sectional dimensions of each of the air ducts is dimensioned such that it is below cutoff for microwave energy at the operating frequency of the cavity 2. In this manner microwave energy is not transferred into the tubular air duct system. A flange 19 is provided at the outer end of the ducts 8 for bolting the air ducts to a suitable exhaust pan or blower, now shown.

The flat multimode cavity of the present invention has many advantages over the prior cavity resonator microwave applicators. Its short height makes it difficult to excite undesired modes of oscillation with the electric vector other than parallel to the broad walls. The short height of the cavity further facilitates directing air flow immediately adjacent the surface of the web or treatment zone. Decreasing the height of the cavity also facilitates impedance matching because, in a higher cavity, the modes would have higher Q, thereby making it more difficult to match the high impedance of the high Q modes to the relatively low output impedance of the microwave source 9. Furthermore, by arranging the waveguide feed with the broad walls of the waveguide 11 perpendicular to the broad walls 3 of the cavity, the desired modes are excited to the exclusion of certain undesired modes. The provision of the lossy mode absorbing element 21 in the joint 12 further suppresses undesired modes.

In addition, the flat multimode cavity of the present invention exhibits all of the advantages of the cavity resonator applicator over the waveguide applicator. It is a physically simple structure which can be fabricated inexpensively, tends to be smaller and lighter in weight and has lower inherent loss than the waveguide type of applicator. As will be apparent it is easy to ventilate and clean and will not tend to collect foreign matter. Finally, it has a sufficient unobstructed volume adjacent the path of the material being treated to minimize the need for careful control over the dimensions and motion of such material.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. In an electromagnetic applicator, a multimode cavity resonator having openings on opposite sides thereof for passing material to be treated with electromagnetic energy through a thin wide treatment zone contained within said cavity, said cavity having a pair of parallel broad walls closed at their side edges by narrow walls with said openings disposed in a pair of said narrow walls and aligned in the plane of the thin wide treatment zone, means for exciting said cavity with

standing waves of electromagnetic of such a class of resonant modes that the electric field vector in the treatment zone is generally parallel to said broad walls of said cavity and lies generally within the plane of the thin wide treatment zone, the spacing between the pair of broad walls of said cavity being at least equal to one-half wavelength and less than one wavelength at the operating frequency of said cavity whereby certain undesired classes of modes are not supported, and being dimensioned to have sufficient length and width to support both the $TE_{l,m,n}$ and $TM_{l,m,n}$ classes of modes of oscillation in said cavity at the frequency of operation where l is 1 and the range of both m and n is greater than 10, said means for exciting said cavity resonator with microwave energy including a hollow rectangular waveguide opening into said cavity at a narrow wall of said cavity, said rectangular waveguide having a pair of broad walls and a pair of narrow sidewalls with the planes of the broad walls of said waveguide being generally perpendicular to the planes of the broad walls of said cavity resonator to preferentially excite in said cavity modes of oscillation having their electric field vectors parallel to the cavity broad walls at the treatment zone.

2. The apparatus of claim 1 including duct means for directing gas into and out of said cavity, said duct means being disposed at said pair of narrow sidewalls which have the openings therein for passage of the material to be treated through the resonator.

3. The apparatus of claim 2 wherein said duct means includes a plurality of adjacent conductive passageways having transverse inside dimensions below cutoff at the operating frequency of said cavity resonator.

4. The apparatus of claim 3 wherein the ducts are arranged to direct a pair of gas streams through said cavity resonator on opposite sides of said treatment zone, with the direction of the gas streams being generally parallel or antiparallel to the direction of movement of the material being treated through said resonator.

5. The apparatus of claim 1 wherein said waveguide opens into said cavity substantially at one of the corners of said cavity.

6. The apparatus of claim 1 wherein said cavity resonator comprises two similar half portions joined together along a joint formed in and disposed intermediate the height of two narrow sidewalls which extend generally in the direction of movement of the material to be treated through said resonator, and means forming a microwave attenuator structure disposed in said joint to suppress undesired classes of modes of oscillation in said cavity.

7. The apparatus of claim 1 wherein means forming an attenuator structure are disposed in said openings in said narrow cavity walls for passing material to be treated to suppress undesired classes of modes of oscillation in said cavity.

8. An electromagnetic applicator comprising an electromagnetic treatment chamber capable of supporting within its interior electromagnetic wave energy and defined by a pair of generally parallel conductive broad walls closed along opposite side edges by narrow conductive sidewalls, the spacing between said pair of broad walls of said cavity being at least equal to one-half wavelength and less than one wavelength at the operating frequency of said electromagnetic wave energy, means for exciting said chamber with electromagnetic energy of a class of modes of oscillation producing electric field vectors in the midplane between and generally parallel to said broad walls, means for supporting at said midplane within said chamber material to be treated with said energy, and lossy mode-damping means extending along each of said sidewalls at said midplane and generally parallel to said broad walls to attenuate any modes within said chamber having at said midplane an electric field vector not parallel to said broad walls.