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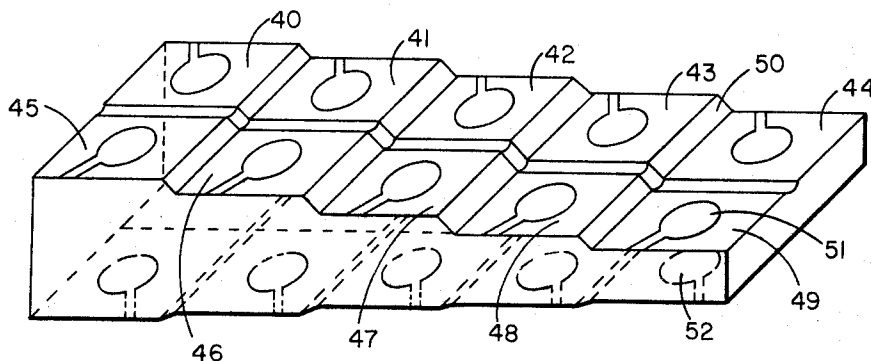
[54] **MONOLITHIC MULTIFREQUENCY RESONATOR**
4 Claims, 6 Drawing Figs.

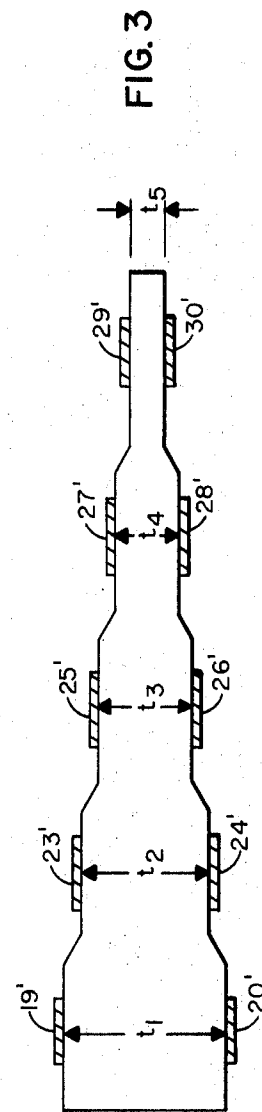
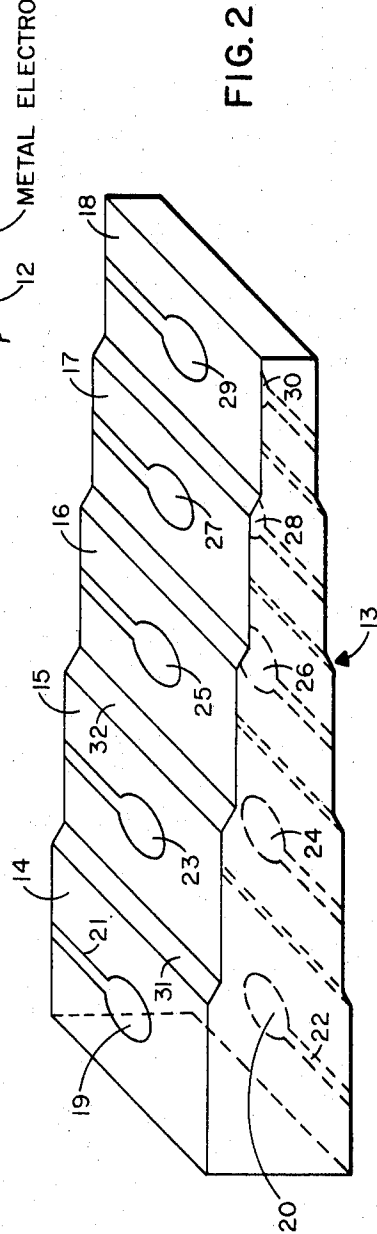
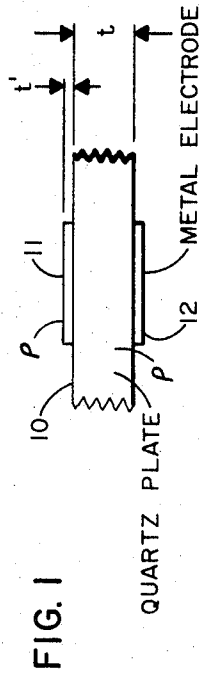
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ABSTRACT: A multifrequency resonating device comprising a single, piezoelectric quartz crystal plate having a plurality of different thickness plateaus formed thereon and separated, one from the other, by sections of beveled surface areas which create acoustic impedance mismatches between the plateaus. Each plateau has coated upon both sides thereof conductive electrodes and suitable terminal leads extending therefrom. Each plateau is resonant at a different frequency without the necessity of separate crystal blank holders or separate temperature compensation circuits.





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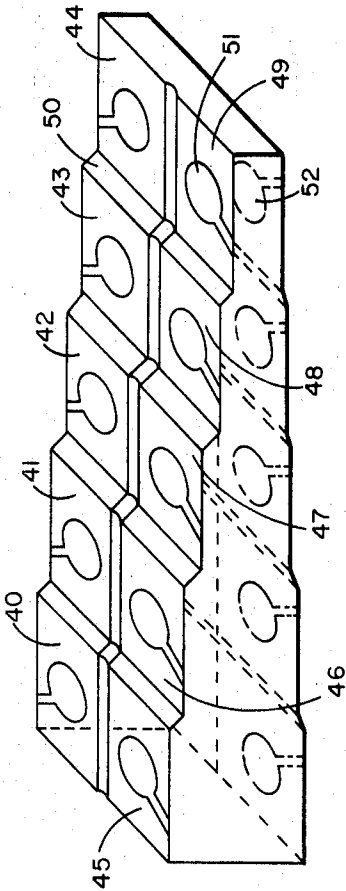


FIG. 4

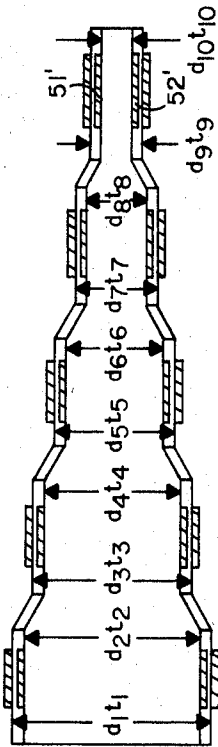


FIG. 5

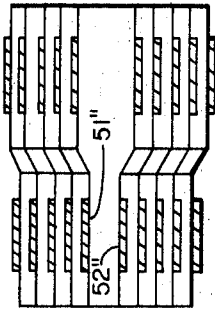


FIG. 6

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MONOLITHIC MULTIFREQUENCY RESONATOR

This invention relates generally to multifrequency resonators, and more particularly to a multifrequency resonator employing a bank of resonators formed on a common or piezoelectric quartz crystal blank.

In the prior art, banks of crystals have long been employed to generate a multiplicity of frequencies. However, in these prior art devices, a separate crystal resonator is usually employed for each given frequency, or a harmonic thereof. The use of separate crystal resonator for each frequency involves a separate holder for each crystal as well as a separate temperature coefficient compensating circuit for each crystal, when temperature compensation is employed. Both the crystal holders and the temperature compensating circuits add appreciably to the expense of the resultant multifrequency resonator bank.

In other types of prior art devices several plated areas have been formed on the same monolithic crystal plate. Such use of the monolithic crystal has been confined largely to either filter-type circuits where the energy transfer between coated areas is either electric or mechanical, or sometimes a combination of the two energy transfer means.

A characteristic of prior art devices using monolithic crystal filters is that the difference in frequency of the various coated areas is determined by the size of the coated area as well as the thickness of the coating. The foregoing is due to the fact that the crystal thickness is substantially uniform, thus limiting the frequency difference of the various resonating areas to that obtainable by changing the size and thickness of the conductive coating.

An object of the present invention is a relatively simple and inexpensive wide range multifrequency resonator employing a single quartz crystal plate.

A second purpose of the invention is a multifrequency resonator employing a single monolithic crystal plate.

A third object of the invention is a multifrequency resonator employing a monolithic crystal means and having a substantially uniform temperature coefficient.

A fourth purpose of the invention is the improvement of multifrequency crystal resonators generally.

In accordance with one form of the invention, there is provided a quartz plate having a multiplicity of sections, or plateaus, of various thickness. Each of these sections or plateaus have their two major surfaces lying in parallel planes, which define the thickness of the section. The two major surfaces of each section have a portion thereof coated with a conductive material. Further, the sections of different thicknesses are separated, one from the other, by areas of changing thickness which are small in comparison with the areas of the plateaus, but yet large enough to provide substantial mechanical isolation between the plateaus. Thus, each plateau constitutes a relatively isolated resonating area of the monolithic crystal.

A feature of the invention lies in the fact that the temperature coefficient for all of the resonating areas is substantially the same since a common crystal plate having a given crystallographic orientation is employed.

A second feature of the invention arises from the fact that the single monolithic crystal needs only a single container or holder whereas in prior art devices each of several crystals require a separate holder.

The above mentioned and other objects and features of the invention will be more fully understood from the following detailed description thereof when read in conjunction with the drawings in which:

FIG. 1 shows a cross section of a plated area of a crystal to facilitate the understanding of the relationship between the various parameters of the structure and its resonating frequency;

FIG. 2 is a perspective view of the invention showing a monolithic crystal having five plateaus;

FIG. 3 is a side view of the structure of FIG. 2;

FIG. 4 is a perspective view of a monolithic quartz crystal having ten plateaus, all of different thicknesses;

FIG. 5 is a side view of the structure of FIG. 4; and

FIG. 6 is an end view of the structure of FIG. 4.

Referring now to FIG. 1, the quartz crystal 10 has a pair of electrodes 11 and 12 coated thereon. The FIG. is included in the specification primarily as a basis of a brief discussion of the factors determining crystal resonant frequency. Said relationship is given approximately by the following expression:

$$f = \left(\frac{1}{2\pi} \right) \left(\frac{C}{t^2 \rho} \right)^{\frac{1}{2}} \left(1 + \frac{2\rho' t'}{\rho t} \right)^{-1}$$

where C is the effective elastic constant in the direction normal to the plane of the crystal plate 10, t is the thickness of plate 10, t' is the thickness of the applied conductive electrodes 11 and 12, ρ is the density of the quartz, and ρ' is the density of electrodes 11 and 12. From the foregoing expression, it is apparent that the frequency of the resonator can be changed by changing the thickness of either the plate 10 or the electrode 11, or by changing the density of the electrode 11. However, compared to the crystalline quartz, the metal electrodes having high internal mechanical friction which results in lowered mechanical Q . There is an optimum thickness for the metal electrodes, which optimum thickness is determined primarily by mechanical characteristics such as the nature of the bonding to the quartz, and also by internal electrical characteristics of the coating, such as the internal resistance thereof. However, any thickness of electrode 11 beyond this optimum thickness results in a decreased Q of the overall structure with resultant damping of the resonance, thus seriously limiting frequency variation obtainable by this technique. Consequently, any appreciable variation frequency is best obtained by changing the thickness of the quartz plate rather than by changing the thickness of the electrode coating.

In FIG. 2 there is shown a perspective view of one form of the invention wherein crystal plate 13 has five plateaus formed thereon, and designated by reference characters 14, 15, 16, 17, and 18. The thickness of each of the five plateaus 14 through 18 is shown in FIG. 3 and designated by characters t_1 through t_5 respectively.

It can readily be seen from FIGS. 2 and 3 that each of the plateaus 14 through 18 consist of two major surfaces upon each of which has been deposited an electrode of conductive material. For example, on plateau 14, electrodes 19 and 20 have been deposited, with input leads 21 and 22 extending respectively from the associated electrode to the edge of the plateau. The leads 21 and 22 are formed by depositing a conductive material on the quartz in a well-known manner.

Each of the remaining four plateaus also have a pair of electrodes and input terminals coated thereon. More specifically, electrodes 23 and 24 are coated upon plateau 15; electrodes 25 and 26 upon plateau 16; electrodes 27 and 28 upon plateau 17; and electrodes 29 and 30 upon plateau 18.

Each of the five plateaus has a different thickness, as shown in FIG. 1 and, consequently, each plateau in combination with the electrodes coated thereon will resonate at a different frequency.

Since frequency is inversely proportional to the thickness of the quartz plate, then the thinnest plateau 18 will have the highest frequency, and the thickest plateau 14 will have the lowest frequency with intermediate frequencies being generated therebetween by plateaus 17, 16, and 15.

It is to be noted that in FIG. 2 and FIG. 3 the relative thicknesses of the plateaus are greatly exaggerated for purposes of illustration. In actual practice, the difference in thickness between adjacent plateaus will be more on the order of micrometers, with the exact difference being determined by the frequency difference desired. With a plateau having a major surface of cross-sectional area equal to 20 sq. mm. a difference in thickness of 0.0043 millimeters will result, for example, in a difference of 600 kHz. at a center frequency of 15 mHz.

Separating each of the plateaus is a beveled surface such as the beveled surface 31 between plateaus 14 and 15, and

beveled surface 32 between plateaus 15 and 16. These beveled surfaces define a slice of the quartz crystal which separates adjacent plateaus and isolates them, one from the other, both mechanically and electrically. The mechanics by which such isolation occurs is well known in the crystal art and will not be described in detail herein other than to state generally that it is primarily a matter of acoustic impedance differences. More specifically, the energy generated at a given frequency plateau 14 for example, cannot pass freely through beveled section 31 into the plateau 15 because the acoustic wave will not propagate in the adjacent region. In essence, the beveled area 31 acts as a bidirectional energy trap, i.e., for both the energy generated in the resonator defined by plateau 15, and the energy generated in the resonator defined by plateau 14.

The multiplateau crystal structure shown in FIGS. 2 and 3 can be manufactured in at least two ways, one of which includes the etching of the plate in either hydrofluoric acid or an ammonium bifluoride solution and the second of which involves a sand blasting operation for different periods of time in order to create plateaus of different thicknesses.

More specifically, in the etching technique the plateaus are created by holding the plate at one end and inserting a given length of it into the solution for a given amount of time to produce a desired thickness change. For example, the crystal plate of FIG. 2 is inserted into the etching solution so that portion of the plate which includes plateaus 15, 16, 17, and 18 are all immersed in the etching solution for a length of time necessary to create the proper thickness for plateau 15. The crystal plate is then pulled out of the etching solution a short distance so that only that length of the plate including plateaus 16, 17, and 18 is immersed in the liquid. Such immersion continues until the plateau 16 obtains its desired thickness.

In a similar manner plateaus 17 and 18 are formed. The beveled surfaces between plateaus can then be perfected to the degree desired by mechanical abrasion means.

In the sand blasting technique, the quartz plates are secured onto a large glass plate by beeswax or other suitable means. The glass plate is then secured onto the periphery of a large wheel which carries the quartz crystal carrying glass plate under the sand blast. At each pass of the wheel, the quartz surface is abraded a small but measurable amount. The region which is not to be abraded is masked off with either a metal shield or a silicone rubber mask which deflects the abrasive. It has been found that the amount of material removed from the quartz crystal with each pass under the abrasive means can be quite accurately predetermined so that the total amount of material removed from the crystal plate is measurable in terms of number of wheel revolutions.

Referring now to FIG. 4, there is shown a perspective view of a monolithic quartz crystal having ten plateaus of different thicknesses which are identified by reference characters 40 through 49. Each of these plateaus is separated from the ad-

jacent plateaus by beveled surfaces such as beveled surface 50. That portion of the crystal defined by a given plateau, resonates, in cooperation with the electrodes thereon, at a frequency in accordance with the thickness of that portion of the crystal.

THE crystal plate configuration shown in FIG. 4 can be formed in a manner similar to that described in connection with FIG. 2 with the following additional steps. The crystal plate of FIG. 4, at some stage in its operation, must be dipped into the etching solution sideways such that the plateaus 45 through 49 define crystal thicknesses less than that defined by the corresponding plateaus 40 through 44.

In FIG. 5, there is shown a side view of the structure of FIG. 4 illustrating the different thicknesses defined by the various plateaus. It is to be understood that each portion of the crystal defined by a plateau must have electrodes of conductive material formed thereon, as in the case of the structure of FIG. 2, in order to complete the resonator.

One such pair of electrodes is identified by reference characters 51 and 52 of FIG. 4 and 51' and 52' in FIG. 5, and reference characters 51'' and 52'' of FIG. 6.

I claim:

1. A mechanical resonating device for generating a plurality of resonant frequencies and comprising:

a monolithic crystal plate having length, width, and thickness, and divided into at least two elongated regions; each of said elongated regions being further divided into sections, with each successive adjacent section in each region having a thickness less than the preceding section in said region, and with the thickness of each section being defined by the major surfaces thereof, which are parallel to each other; and

opposing conductive electrode means formed on said sections; each of said sections being resonant at a given frequency different from the resonant frequencies of other sections.

2. A mechanical resonating device in accordance with claim 1 in which said sections of said monolithic crystal plate are separated one from the other by segments of said crystal plate positioned therebetween with their exposed surfaces providing a beveled transition between the different thicknesses of adjacent sections.

3. A mechanical resonating device in accordance with claim 1 in which each section of each region, except the thickest and the thinnest portions of the crystal plate, have a thickness greater than one and less than the other of two adjacent sections in the same region and in the adjacent region.

4. A mechanical resonating device in accordance with claim 3 in which said sections of said monolithic crystal plate are separated one from the other by segments of said crystal blank positioned therebetween with their exposed surfaces providing a beveled transition between the different thicknesses of adjacent portions.