

March 4, 1969

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3,431,392

INTERNALLY HEATED CRYSTAL DEVICES

Filed Jan. 13, 1967

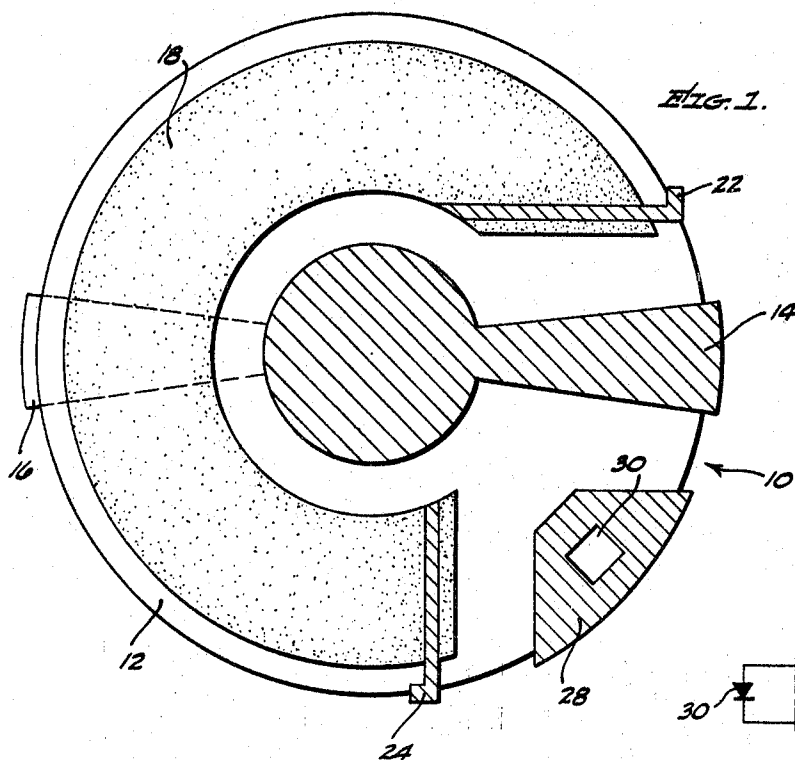


FIG. 1.

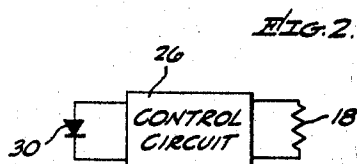


FIG. 2.

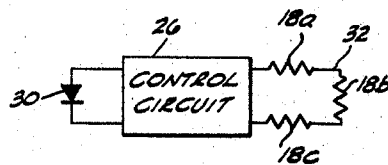


FIG. 4.

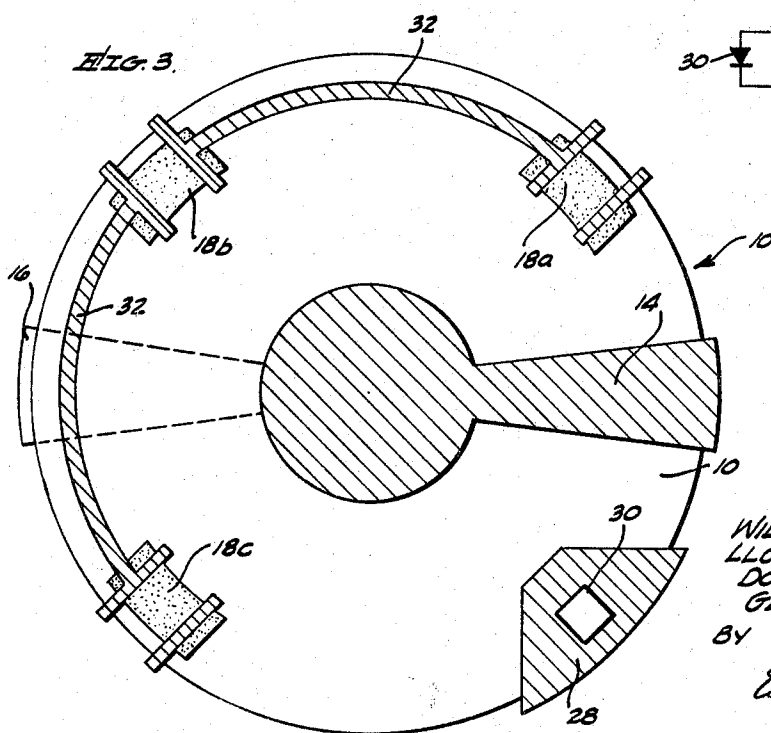


FIG. 3.

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INTERNALLY HEATED CRYSTAL DEVICES

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Filed Jan. 13, 1967, Ser. No. 609,033

U.S. Cl. 219-210

15 Claims

Int. Cl. H05b 3/06

ABSTRACT OF THE DISCLOSURE

A crystal resonator with a heating device and a thermal sensor placed directly upon the crystal wafer, thus the temperature of the heating element is controlled by the thermal sensor through control circuitry.

This invention relates to piezoelectric devices and more particularly to a novel and improved crystal resonator device or the like which is internally temperature stabilized.

Crystal resonators such as those constructed of piezoelectric materials are usually hermetically sealed in containers filled with an inert gas such as nitrogen or helium to prevent contamination of the material. The crystal may have a pair of electrodes disposed on either side to form a resonator when subjected to an electric field. It is known that the resonant frequency of such devices varies with temperature and thus it is necessary to maintain a constant temperature of the crystal to stabilize the frequency. This becomes important when precision equipment is used wherein the required temperature limits or temperature ranges are as narrow as 1° or 2° F.

In the prior art, temperatures of the crystal have been maintained by ovens, external heaters or heat transfer panels.

Such thermal control conditions normally surround or otherwise contact a crystal device externally. These prior art thermal control systems have a disadvantage in that the weight and volume required are each typically two or three times those of the crystal device, and in some situations this ratio can be much higher.

A further disadvantage of these prior art devices is that a substantial part of the heat transferred by the thermal control equipment is lost to other components. Usually more than one-half of the total heat input is transferred to components other than the control device.

Another disadvantage is that the thermal time constants are typically high. An overall thermal time constant of a crystal with respect to fluid inlet temperatures in a cold wall system can be, in some cases, quite high, i.e. 15 or 20 minutes. It has been found that even if a coil of heater wire is wrapped directly around a crystal container for essentially eliminating all external thermal resistance, the built-in time constant of the device is still on the order of a couple of minutes. This built-in time constant is a product of the thermal mass of the crystal element and the parallel combination of thermal resistance of the container, its components and the resistance of the inert gas.

It has been found that close control of the temperature in these prior art devices is quite difficult because of thermal lags between external heat exchangers, external sensors and the crystal.

The present invention comprises a thermal sensor, control amplifier and a heater. The sensor is disposed directly upon the surface of the crystal resonator and the heater element is formed by depositing a resistive element directly upon the surface of the crystal. Inter-connection is then made between the resistive heater element and the sensor to an external control circuit.

A feature of this invention is that there is no increase in the physical volume of the device and only a very small increase in the weight with the addition of the internal thermal control to the crystal device.

A further advantage is that the that is applied directly to the resonator element and only a few percent of total power dissipation is lost to external thermal mass. Further, by this invention, thermal time constants are only a few seconds with respect to the minutes required in the prior art. By reducing warmup time in this manner, the equipment used with this particular device can be in a ready condition without requiring that the associated electronics be maintained in a standby operating condition. This will reduce the power consumption and increase the system reliability.

A still further advantage of this device is that a close control is now possible (i.e. ± 0.1 F.), and this is because heaters and sensors are located directly on the controlled element and thermal lags are reduced.

It therefore becomes one object of this invention to provide a novel and improved crystal device which is internally temperature controlled.

Another object of this invention is to provide a novel and improved internally heated crystal device which exhibits a very small heat loss to external thermal mass.

Another object of this invention is to provide a novel and improved temperature controlled crystal device without an increase in overall size and thereby compatible with microminiature circuit techniques.

Another object of this invention is to provide a novel and improved internally heated crystal device which includes a heat regulating sensing device disposed upon the crystal wafer for controlling the temperature thereof.

These and other objects, features and advantages will become readily apparent to those skilled in the art when taken into consideration with the following detailed description in conjunction with the drawings in which:

FIGURE 1 illustrates one preferred embodiment of this invention showing the various elements disposed upon the crystal wafer;

FIGURE 2 is a schematic circuit of the embodiment shown in FIGURE 1;

FIGURE 3 illustrates a second embodiment of this invention; and

FIGURE 4 is a schematic circuit of the embodiment shown in FIGURE 3.

Turning now to a more detailed description of the embodiment shown in FIGURE 1, a crystal device 10 is illustrated as a crystal resonator and comprises an AT cut quartz crystal wafer 12 and a pair of electrodes 14 and 16 disposed on either side thereof to form the crystal device 10. The operation of crystal resonators such as shown in these embodiments are well known in the art and provide a frequency output when electrodes 14 and 16 are exposed to an electric field. Because of the fact that these crystal resonators are well known in the art, no attempt will be made herein to explain their operation.

A heater element 18 in the form of a resistive element is deposited upon one face of crystal wafer 12. In one embodiment resistive element 18 is composed of Nichrome at 200 angstroms thick. This, of course, can be of any resistive material and is not limited to the Nichrome. A pair of conductive elements 22 and 24 is placed in a contiguous relationship on either end of heater element 18 to provide lead lines to external control equipment 26, as shown in FIGURE 2. In a preferred embodiment, conductors 22 and 24 were composed of aluminum at 10^{-4} cm. thick.

A metallic material 28 is placed upon crystal wafer 12 and a sensor device 30 is affixed to metallic material 28. In a preferred embodiment, sensor device 30 may be

a semi-conductor chip, or a thin film sensor element such as a resistive material similar to the Nichrome used for the heating element 18. The resistive sensing element may be thinner, say 50 angstroms for example, to have high temperature co-efficient.

The conductivity of the sensor 30 varies proportionately with temperature and when operating in conjunction with the control circuit 26, the proportion will be inversely related to power applied from the control device across heating element 18. Hence, crystal wafer 12 maintains a stable, constant temperature. Sensor 30 may be in the form of a transistor chip and the temperature sensitivity is detected by the change in V_{be} . This voltage change can then be detected by control circuit 26 and a change is made to the voltage applied across resistive element 18.

The adherence of the specific metallic material to the surface of crystal wafer 12 may be accomplished by the vapor deposition process while sensor 30 may be affixed to the metallic material 28 by a bonding process. It has been found that for best results semiconductor chips, such as sensor 30, can be more firmly affixed if first the metallic substance is laid down, because semiconductor chips are not easily bonded to the surfaces of crystal wafer 12.

FIGURE 3 illustrates a second embodiment of this invention wherein heater element 18 comprises a plurality of deposited resistive elements and in the embodiments in FIGURE 3 there are three elements, 18A, 18B and 18C. Each of resistive elements 18A, 18B and 18C are coupled in series by leads 32. These leads 32 may also be deposited directly upon the crystal wafer 12 after the heater elements 18A, 18B and 18C have been laid down.

The single heater element model as shown in FIGURE 1 provides for more uniform distribution of heat than does the three heater element model as shown in FIGURE 3, while the latter model allows flexibility of interconnection of the heater elements. FIGURE 4 illustrates the schematic equivalent circuit of the embodiment shown in FIGURE 3, and the interconnecting techniques required thereof.

Thus, it can be seen that the objects of this invention are accomplished wherein an internally heated crystal resonator is provided which is more efficient and more compatible for operation with microminiature circuit techniques. Too, a device is provided which includes a sensor which is disposed upon the crystal wafer 12 to control the temperature thereof by regulating the voltage applied across the heating element 18.

Having thus described only preferred embodiments of this invention, what is claimed is:

1. An internally heated crystal device comprising:
 - a crystal resonator device, said device including a crystal wafer substrate;
 - a thermal sensor, said sensor being disposed upon said crystal wafer substrate; and
 - a heater element, said heater element being disposed in contiguous relation with said crystal wafer substrate and interconnected with said sensor for regulating the temperature of said crystal wafer substrate.
2. The internally heated crystal device as defined in claim 1 wherein said heater element comprises a resistive element being disposed upon said crystal wafer substrate.
3. The internally heated crystal device as defined in claimed 1 wherein said sensor being a semiconductor chip.
4. The internally heated crystal device as defined in claim 1 wherein said heater element comprises a resistive element being disposed upon said crystal wafer substrate and wherein said sensor is a semiconductor chip affixed to said crystal wafer substrate.

5. The internally heated crystal device as defined in claim 1 wherein said heater element comprises a plurality of series connected thin film resistive elements disposed upon the surface of said crystal wafer substrate.

6. The internally heated crystal device as defined in claim 1 wherein said thermal element is composed of a resistive material.

7. An internally heated crystal device comprising:

- a cut crystal wafer forming a substrate;
- electrode means disposed on said crystal wafer for forming in conjunction with said crystal substrate an electrical frequency resonator;
- a heating device disposed upon the surface of said crystal wafer for maintaining a controllable temperature of said electrical frequency resonator, said heating device including a thin film resistive material disposed upon the surface of said wafer;
- a thermal sensor device affixed to said wafer; and
- control means for controlling the constant temperature to said heater element, said control means being coupled to said heating device and responsive to said heating device and thereby stabilizing the frequency of said resonator.

8. The internally heated crystal device as defined in claim 6 wherein the sensor device is a semi-conductor chip affixed to the surface of said substrate.

9. The internally heated crystal device as defined in claim 6 wherein said heater element includes a plurality of independently disposed resistive thin film elements deposited upon the surface of said substrate at various locations, and interconnecting conductive material disposed between said resistive elements for serially coupling the resistive elements in series.

10. The internally heated crystal device as defined in claim 6 wherein said thermal sensor device is composed of a resistive material disposed upon the surface of said crystal wafer, said resistive material having a relatively high temperature co-efficient.

11. The method of forming an internally heated crystal resonator comprising the steps of:

- forming a crystal resonator on a crystal wafer substrate;
- disposing a thermal sensor upon one surface of said substrate;
- disposing a heater element in contiguous relation with said crystal wafer substrate; and
- interconnecting said sensor with said heater element.

12. The method as defined in claim 11 and further comprising the steps of controlling said heater element at a constant temperature for stabilizing the frequency of said resonator.

13. The method as defined in claim 12 wherein said thermal sensor is a semiconductor chip.

14. The method as defined in claim 12 wherein said heater element is a resistive element.

15. The method as defined in claim 12 wherein said heater element is a resistive device and said thermal sensor is a semiconductor chip.

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U.S. Cl. X.R.

219—501, 510, 543; 310—8.9