

[54] **CONTACT HEATERS FOR QUARTZ CRYSTALS IN EVACUATED ENCLOSURES**

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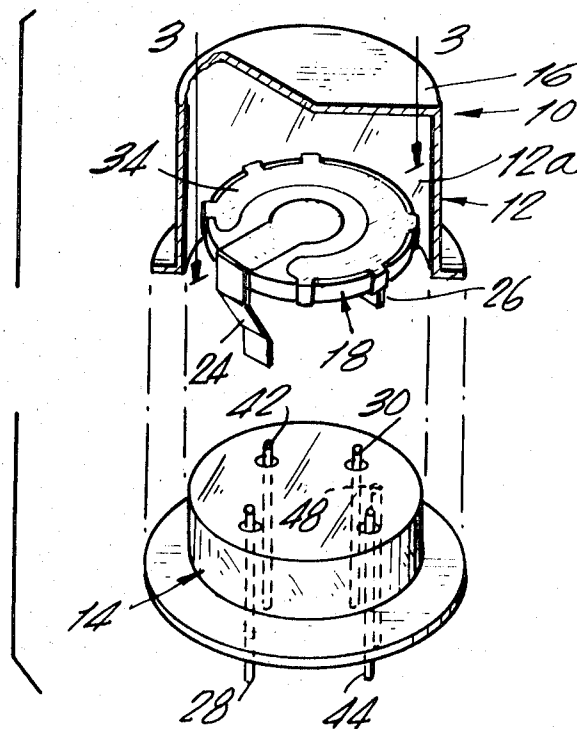
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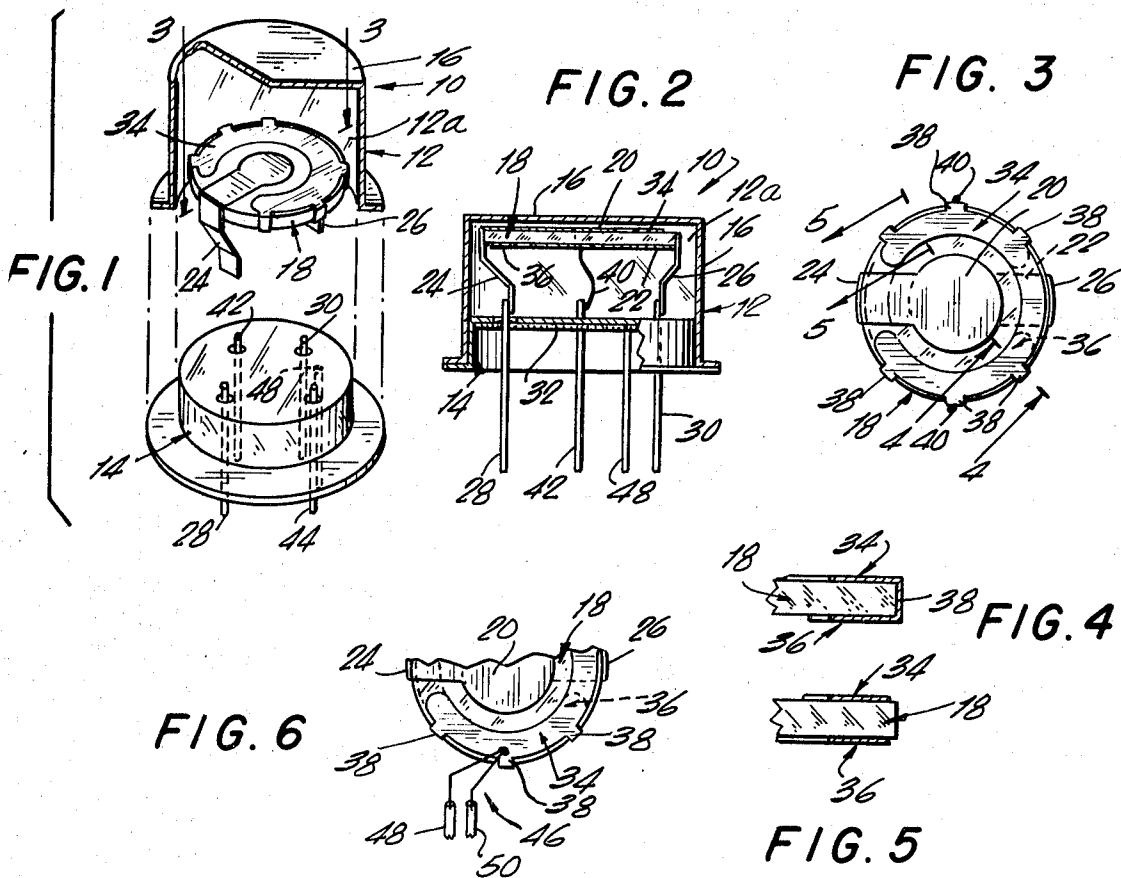
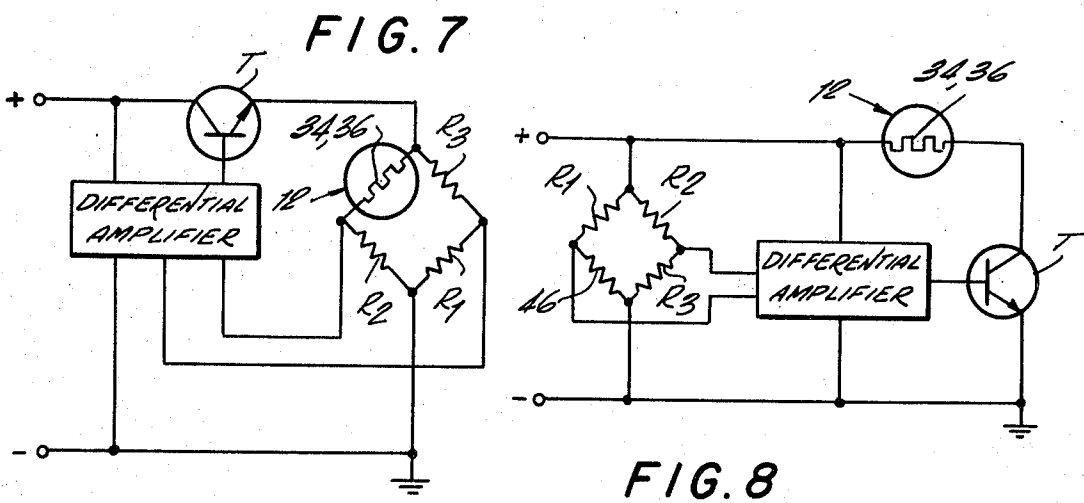
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[57] **ABSTRACT**

Thin metallic films are deposited on surfaces of quartz crystals in selected patterns and appropriate leads are provided to pass a current through the metallic film in order to heat same and thereby heat the crystals. The crystals are mounted in normal manner to an evacuated chamber. By use of the thin film contact heaters, temperature equilibrium is achieved at a much faster rate of time, with a higher rate of stability and with substantially reduced power consumption.

1 Claim, 8 Drawing Figures





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CONTACT HEATERS FOR QUARTZ CRYSTALS IN EVACUATED ENCLOSURES

The present invention relates generally to constructions for piezoelectric devices and specifically the means for achieving direct and improved temperature control of piezoelectric devices such as quartz crystals. Such crystals are known to be temperature sensitive and therefore they have been traditionally placed in fine tolerance ovens which maintain their temperature to a high degree of accuracy, thereby to stabilize the oscillation frequency of the crystal. Although such devices have been successful in the past, their construction, as known to date, results in products which are larger than desired, which have power consumptions greater than desired and which display time periods for reaching equilibrium temperature longer than desired.

Investigations have disclosed that a variation in the manner in which heat is introduced can substantially improve the performance characteristics of these devices. Rather than by use of the conventional ovens known to date, it has been determined that a system of thin film deposits, directly on the crystals, can be utilized as electric resistance heaters to produce substantially improved results.

Accordingly, it is an object of the present invention to provide new and improved means for heating piezoelectric devices. More specifically, it is an intended object of the present invention to provide a structure in association with a piezoelectric crystal, such as a quartz crystal, wherein the crystal is directly heated by an electrical resistance heater comprising a thin film deposited on the crystal.

It is further within the contemplation of the present invention to provide a piezoelectric crystal device in which an equilibrium operating temperature can be achieved at an improved rate and stabilization achieved and maintained with low power consumption.

It is still further within the contemplation of the present invention to provide such a device with an efficiently operating heater which is inherently free from impurities which might migrate into the crystal material.

It is finally and generally an object of the present invention to provide an improved quartz crystal device in an evacuated enclosure.

In accordance with one presently preferred embodiment of the invention, there is provided a piezoelectric oscillator device which includes a vessel in which is formed an evacuated chamber. Mounted within the chamber is a piezoelectric crystal having electrodes for exciting the crystal and lead wires attached to those electrodes and extending outwardly through the walls of the vessel. Means for controlling the temperature and temperature stability of the crystal are provided and comprise a thin film, vacuum-deposited, electrically resistive heater element in intimate engagement with and upon the surface of the crystal. The heater element is generally patterned to follow the periphery of the crystal itself. Lead wires are operatively engaged with the heater element to provide a source of current to flow through the heater element and those lead wires extend through the walls of the vessel to the outside to be connected with a source of power. Power control means are also provided to govern the flow of power through the heater element and include temperature

sensing means to determine the temperature of the piezoelectric crystal and to adjust the power flow responsive to temperature measurements.

The above brief description, as well as further objects, features and advantages of the present invention, will be best understood by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

FIG. 1 is an exploded elevational view, with portions broken away for the sake of clarity, of a complete piezoelectric electric device made in accordance with the present invention including an evacuated chamber, lead pins extending through the walls of the chamber, a crystal mounted within the chamber and contact heater means engaged with the crystal;

FIG. 2 is a side sectional view of the device shown in FIG. 1 in its completely assembled configuration;

FIG. 3 is a sectional view taken along the line 3—3 of FIG. 1 looking in the direction of the arrows and is, therefore, a plan view of the crystal;

FIG. 4 is a sectional view taken along the line 4—4 of FIG. 3 looking in the direction of the arrows;

FIG. 5 is a sectional view taken along the line 5—5 of FIG. 3 looking in the direction of the arrows;

FIG. 6 is a partial view similar to that of FIG. 3 showing an alternate addition of a temperature sensing device such as a thermistor with its appropriate lead wires;

FIG. 7 is a schematic of a control circuit in which the variation in resistance of the heater as a function of temperature is utilized in a control circuit for a delivery of power to the heater; and

FIG. 8 is a schematic diagram of a control circuit for power delivery to the heater dependent upon variations and resistivity of an external temperature sensing device such as a thermistor.

Referring now to FIGS. 1 and 2, there is shown a precision oscillator device generally designated by the numeral 10. The device utilizes an evacuated vessel 12 formed by a metallic base 14 and metallic cap 16 which provide an internal chamber 12a. Specifically, the base 14 has a skirt and shoulder which conform to the skirt and internal diameter of the cap 16 such that the vessel 12 can be evacuated and the two halves joined together with an airtight seal. Mounted within the chamber 12a is a piezoelectric device generally designated by the numeral 18. The device in this illustrative embodiment is a piezoelectric crystal of planar disc shape. It is provided with standard electrodes or contacts 20, 22 for impressing the excitation voltage thereon and it is mounted within the chamber 12a by means of lead contacts 24, 26 attached to the electrodes 20, 22 respectively. The lead contacts 24, 26 extend to the contact pins 28, 30 which pass through airtight openings in the bottom wall of the base 14. In the usual fashion, a layer of ceramic material 32 is provided to insure an airtight seal at the point where the lead wires pass through the wall of the vessel 12. The foregoing is generally descriptive of the prior art as well as the environment of the present invention.

Since oscillators such as the quartz crystal 18 are temperature sensitive, in order to produce a precision signal, it is necessary that the temperature of the device be elevated to a desirable operating temperature and that the operating temperature be maintained within

very narrow limits even where there are significant variations in the ambient temperature. In order to heat the crystal 18, and in accordance with the present invention, there is formed around the periphery of the crystal 18 a direct heater structure 34, 36, the configuration of which is best seen in FIGS. 3, 4 and 5. One portion of the heater is applied on one surface of the crystal 18 and another portion is applied on the opposite side. Both portions of the heater are applied adjacent the periphery of the crystal 18 and extend around the greater portion of the edge of the device. When a source of direct current is caused to flow through the heaters, they heat up and thus raise the temperature of the host crystal 18. It has been found that these contact heaters operate most efficiently when arranged in patterns substantially as shown in FIG. 3, wherein the heaters occupy the area adjacent the periphery of the device. In the present embodiment, a series of interconnecting legs 38 are formed to interconnect the heaters 34, 36 in a parallel electrical resistance arrangement. Heater lead wires 40 are connected to the heaters 34, 36 at opposite points and are connected, in turn, to heater lead pins 42, 44 on the base 14 through which direct current is delivered to the heaters 34, 36. It will be appreciated that the interconnecting arms 38 essentially create an array of resistance heaters in parallel circuitry. Elimination of some of the interconnecting arms would decrease the number of parallel branches and would thereby increase the resistance of each individual branch. Alternatively, the heaters could be arranged in a series circuit thus increasing the total resistance as seen from the heater lead pins 42, 44. The preferred value of the resistance is a design function and the disclosed structure allows for as wide a variation as possible. It has been found that resistance values in the range of 300 ohms provide good results.

As may be best seen in FIG. 5, the heaters 34, 36 are applied directly to the surface of the crystal 18 and, in this embodiment, are of the shape of an incomplete circular band immediately adjacent the periphery of the crystal. As shown in FIG. 4, the connecting arms 38 are integrally formed with the heater elements 34, 36. The material of the heaters 34, 36 and the connecting arms 38 may be selected from a large variety of metallic elements and alloys or any other material which can be formed into a thin layer and which will produce heat when traversed by electric current. It has been found that nickel and platinum both perform well for this function but that aluminum does not react quite as well because of unsatisfactory results with regard to heater resistance stability. The heaters are preferably deposited by conventional vacuum depositing of thin metallic film. Vacuum deposition is, of course, a well known procedure in this technology.

The structure of the entire device 10 is designed to minimize heat loss. Convection losses through space around the crystal 18 are virtually eliminated because of the evacuation of the chamber 12a. Radiation losses are extremely small because of the polished interior surfaces of a base 14 and cap 16 of the evacuated vessel. The majority of any heat losses which do exist occur through the various lead wires and, to minimize these losses, those lead wires are made as thin and long as possible consistent with electrical and mechanical requirements.

Means are provided within the crystal device 10 to control the flow of electrical power to the heaters 34, 36. In some relatively rare instances, the only control necessary is a preset, non-varying control which determines the amount of power which will flow into the heater. For example, in an installation to be operated under a large body of water where the ambient can be considered to be essentially of zero temperature variation, the power input can be designed to hold the temperature of the crystal at the desired operating temperature with due consideration being given to heat losses at the equilibrium state. However, in most instances, there will be significant ambient temperature variations, or other parameters such as a requirement for a fast heat up capacity, and thus means are provided to continuously sense the temperature of the device and responsively vary power input to the heaters. Temperature sensing means are employed within the device to continuously measure the temperature and the information that is derived is used to control the amount of power delivered to the contact heaters. In FIG. 6, there is shown, in schematic form, a thermistor 46 located on the heater immediately adjacent its connection to the heater lead wire 40. The thermistor can be placed at a variety of locations and it has been found that it is advantageous to place it on the heater adjacent the heater lead wire or on the heater lead wire itself in order to make it sensitive to heat losses as they occur by conduction along the lead wires. Appropriate lead wires extend from the thermistor 46, one of which goes to the pin 48 and another to the pin 50. The pin 48 is shown in FIGS. 1 and 2 as being a vessel grounding pin and the other pin 50 may either be the same pin as one of those already described or may be an additional pin passing through the wall of the evacuated chamber. It will be appreciated, of course, that the showing in FIG. 6 of the thermistor and its electrical and mechanical connections is schematic in nature.

FIGS. 7 and 8 present two different schematics of the control circuitry in which power to the contact heater is controlled as a function of the temperature in the device. In FIG. 7 a circuit is shown in which the variation and resistivity of the contact heater itself is used as the temperature sensing element and in FIG. 8 the schematic depicts the use of a device such as the thermistor 46.

In the schematic drawing of FIG. 7, there is shown a heater 34, 36 arranged in a four-arm bridge along with small temperature coefficient resistors R1, R2 and R3 which may be, for example, Corning Glass C style resistors which have a temperature coefficient of $0.1 \times 10^{-3}/^{\circ}\text{C}$. The heater 34, 36 may be either platinum or nickel, the temperature coefficients of which are given as $3.9 \times 10^{-3}/^{\circ}\text{C}$ and $6.17 \times 10^{-3}/^{\circ}\text{C}$, respectively. The differential amplifier reads the voltage difference between the centers of the two branches of the bridge and, through the transistor T, controls the heating power delivered to the heaters.

The schematic of FIG. 8 is similar to that of FIG. 7 except that rather than utilize the heater material as the temperature sensing device, a thermistor 46 is utilized as one of the legs of the four-arm bridge. Again, a differential amplifier senses the difference in voltage between the two branches of the bridge and through the transistor T controls the power delivered to the heater 34, 36.

Experimental details utilizing the concepts of this invention have been given in a paper entitled "The Direct Temperature Control of Quartz Crystals in Evacuated Enclosures" by Tinta, Matistic and Lagasse which was published at the frequency and time control symposium sponsored by the U. S. Electronic Command during the week following Apr. 25, 1970. The data and disclosure of that paper may be referred to for further details and it is incorporated here by reference.

It will be appreciated that in accordance with the present invention there is provided a mechanism for the direct introduction of heat to a piezoelectric device. Rather than by heating an oven to indirectly heat a crystal, the crystal itself becomes the element heated through direct contact with a electrically resistive thin film applied to the crystal by vacuum deposition techniques. With the mounting of the crystal within an evacuated chamber, with proper attention being paid to minimize conduction and radiation losses, there is produced a small structure of high dependability which requires lower power consumption which achieves temperature equilibrium quickly and which requires very low power to maintain temperature equilibrium, even with significant ambient temperature variations. Investigation has shown that devices in accordance with the present invention have been able to

maintain critical operating temperature with variations in ambient temperature far more reliably at much less power consumption than were available in the prior art.

Only one specific configuration for a thin film contact heater has been illustrated. It will be obvious to those skilled in the art that a variety of geometrics for contact heaters as disclosed herein may be used on a variety of crystal configurations.

What I claim is:

1. In a piezoelectric resonator of the type having a piezoelectric crystal mounted within an evacuated chamber through the walls of which said crystal is supplied with excitation electrodes, the improvement comprising: a thin film, metallic, electric resistance heater formed on and in intimate contact with a portion of the surface of said crystal; means for sensing changes in temperature of said crystal; electric power means for delivering a source of current to said heater; and control means responsive to said temperature sensing means for controlling the power delivered to said heater dependent upon the temperature of said crystal; said heater being formed of a positive coefficient resistance material and said temperature sensing means includes a resistance bridge which utilizes said positive coefficient resistance heater as one element thereof.

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