ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E8-96-310

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THERMOSENSITIVE QUARTZ RESONATORS AT CRYOGENIC TEMPERATURES

Submitted to the 10th European Conference on Solid-State Transducers,
September 8—11, 1996, Leuven, Belgium

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1996

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Термочувствительный кварцевый резонатор при криогенных температурах

Изучены частотно-температурные характеристики термочувствительных кварцевых резонаторов (yxbl/10° 54′/11° 06′ — срез) при температурах от 300 K до 4,2 K. В области 300—170 K сохранялся линейный характер зависимости частоты от температуры, с понижением температуры наблюдалась нелинейная характеристика, которая может быть аппроксимирована полиномом 3 степени. Резонаторы имеют высокую чувствительность по температуре: 80 mK при 4,2 K и 1 mK при температурах выше 30 K, и нечувствительны к магнитным полям. Проведенные исследования показали, что термочувствительный резонатор может быть использован в качестве высокочувствительного термодатчика при криогенных температурах.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1996

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Thermosensitive Quartz Resonators at Cryogenic Temperatures

The temperature-frequency characteristics (TFC) of thermosensitive quartz resonators (yxbl/10° 54′/11° 06′ — cut) are investigated over a temperature range from 300K to 4.2K. The TFC linear character is kept within a range from 300K to 170K. As temperature decreases, we observe the nonlinearity which can be approximated by a polynom of the 3-rd order. The resonators have a high temperature sensitivity: 80 mK at 4.2K and 1 mK at a temperature over 30K, and they are insensitive to magnetic fields. The investigations show that the temperature-sensitive sensor can be used as a temperature sensor for cryogenic temperatures.

The investigation has been performed at the Laboratory of High Energies, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1996

1. Introduction

Due to the features of quartz monocrystals, they take a special position in comparison with other piezoelectric materials. They are nearly an ideal elastic body, which keeps its elastic properties to the limits of its mechanical resistance and possesses a very small internal friction resulting in a slow attenuation of free vibrations. The most important advantage of quartz is its anisotropy allowing the consruction of piezoresonance devices which possess either a negligible or a strong temperature frequency dependence. Bechmann and others [1] have experimentally proved that the TFC of each resonator can be presented by a polynom of the n-th order and takes the form of a straight line, a quadratic (BT, DT, CT-cuts) or a cubic parabola (AT-cuts). The frequency dependence on temperature can be presented by a polynom of the 3-rd order with an accuracy acceptable for practice over an interval from minus 200° C to 200° C [2]. A family of different thermostable quartz resonators used for telecommunication was developed on this basis during the last 50 years [3]. The first thermosensitive resonators with linear TFC in an interval from minus 80° C to 250° C were also developed during the last 10 - 20 years [4]. A new type of thermosensitive quartz resonator (yxbl/10° 54′ /11° 06′ - cut) was designed at the Acoustoelectronics Laboratory of the Institute of Solid State Physics of the Bulgarian Academy of Sciences [5]. This resonator has a linear TFC and high thermosensitivity over a temperature range from minus 40° C to 200° C. The aim of this paper is to investigate the efficiency of this thermosensitive quartz resonator at a temperature of 4.2 K and some basic characteristics.

2. Experiment

All the investingations of thermosensitive quartz resonators at cryogenic temperatures were made at the Laboratory of High Energies of the Joint Institute for Nucear Research, Dubna, Russia. The experimental setup used to measure the TFC is shown in fig.1.

The TFC at cryogenic temperatures were measured using a special helium vessel (1) equipped with a stick. The thermosensitive quartz resonator (3) and the carbon thermoresistor (2) for temperature measurement were attached to this stick. The actual temperature T was calculated from the measured resistance of the thermoresistor, using the calibration curve T(R). The quartz thermosensitive resonator was connected to the measuring oscillator (MO) by a highfrequency matching cable. The generated frequency was measured by a digital electric frequency counter 43-63/1 with an instability of less than 10^{-3} /hour.

Using the vertical movement of the stick, the temperature of the quartz thermosensitive resonator and the carbon resistor changed from room temperarure to 4.2K.

The influence of the magnetic field on the resonanse frequency of the quartz resonator was measured by a special facility with a superconductive coil (4) creating magnetic fielfds up to 4.5T.

3. Results of preliminary investigations

The first results from the investigations of the thermosensitive quartz resonators at cryogenic temperatures show that the resonators operate steadily and without interruption or jumping to another frequency within the whole temperature range from 300 K to 4.2 K. The TFC remain linear, and the resonators keep high termosensitivity (C_t = 1000 Hz/K) down to a temperature of about 170 K (fig.2). Below 170K, the TFC has a nonlinear character, but the resonator still keeps its high sensitivity (fig. 3). The temperature sensitivity is 190 Hz/K at 170K, 60 Hz/K at 20K, 5.2 Hz/K at 10K, and 2.3 Hz/K at 4.2K.

The short-term instability of the quartz resonator frequency at helium temperature was also investigated. The experiments proved that the frequency fluctuation, as a result of all destabilization factors, did not exceed 0.4 Hz for a 10-minute time interval (fig.4). These factors include the frequency fluctuation of the time base of the frequency counter, frequency variation in the thermosensitive resonator itself, as well as temperature variations in liquid helium.

This high short-term stability (of $1.5 \bullet 10^{-8}$) allows the measurement of temperature fluctuations with the following sensitivity:

$$\Delta T_{min} = 80 \text{ mK at } 4.2 \text{ K},$$

$$\Delta T_{min} = 20 \text{ mK at } 10 \text{ K},$$

$$\Delta T_{min} = 2 \text{ mK at } 20 \text{ K and}$$

$$\Delta T_{min} = 0.2 \text{mK at } 170 \text{ K}.$$

The setup shown in fig.1 was used as a base arrangement for the investigation of the influence of the magnetic field on the resonance frequency of the quartz thermosensitive resonators. A superconductive coil is used to create a magnetic field of about 4.5 T. All measurements of the resonance frequency dependence on the applied magnetic field H were made at helium temperature (T=4.23K).

The results of the perfomed investigations show that magnetic fields from 1 to 4.5T have no influence on the resonance frequency of the quartz resonator (fig.5). A disturbance in the resonance frequency of the quartz resonator was registered by turning on a superconducting coil supply (at H=0 T). It is probably caused by an electric disturbance in the measuring oscillator due to power supply to the superconductive coil. For comparison, the changing resistance of the carbon thermoresistor (at T = const) under the magnetic field influence is shown in the same figure. The resistance R grows with increasing the magnetic field.

4. Conclusions

The results obtained by the preliminary investigations of the quartz thermosensitive resonators at cryogenic temperatures show that they keep their efficiency within the whole temperature range from 300K to 4.2K. For temperatures below 170K, the TFC have a nonlinear character, and temperature sensitivity decreases with decreasing temperature. Nevertheless, the quartz resonators can register the temperature fluctuation ΔT_{min} = 0.08K at 4.2K because of high short-term stability and relatively high temperature sensitivity. This temperature sensitivity of the resonator, the independence of its resonance frequency of the magnetic field presence and a high-frequency output signal convenient for digital information treatment show that the thermosensitive quartz resonator possesses a considerable potential for its application as a quartz thermosensor for cryogenic temperatures, as well. For this purpose, it is necessary to examine in

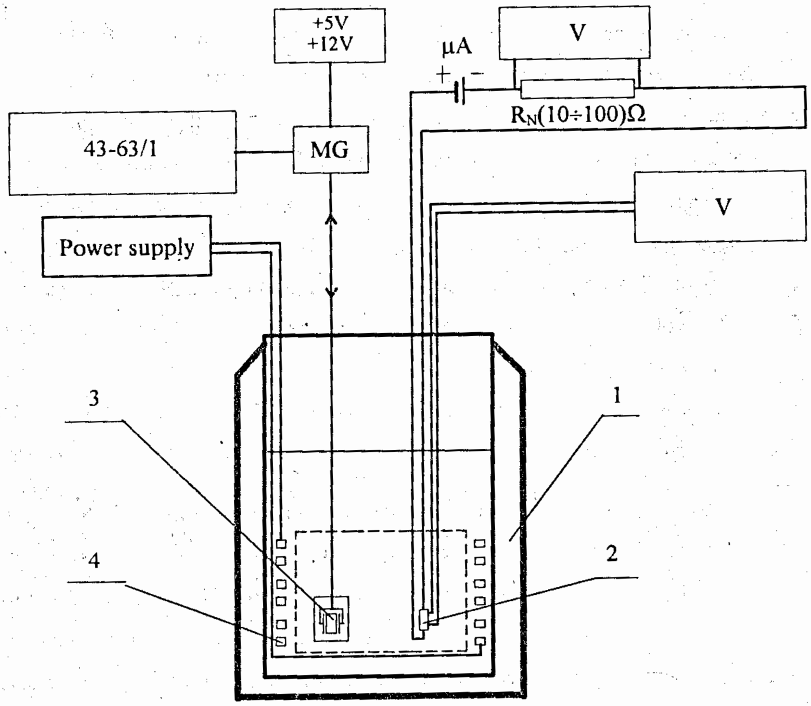

Fig. 1

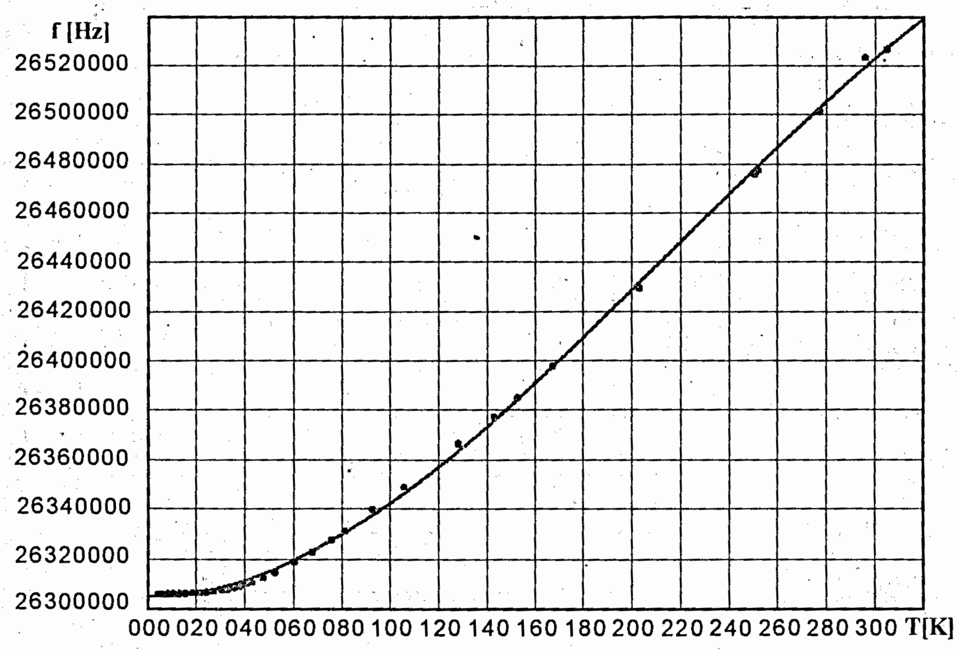

Fig. 2

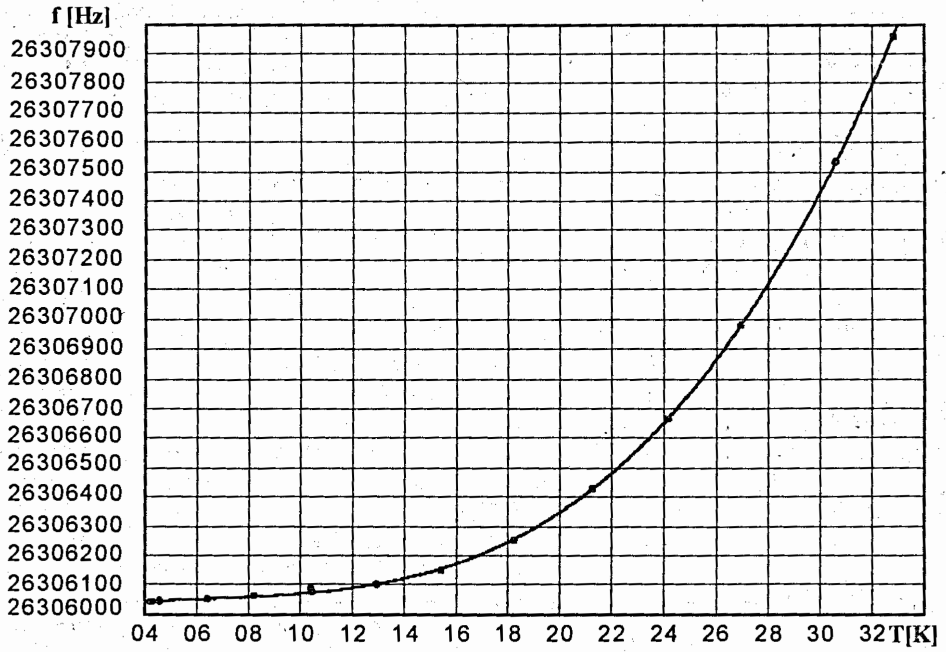

Fig.3

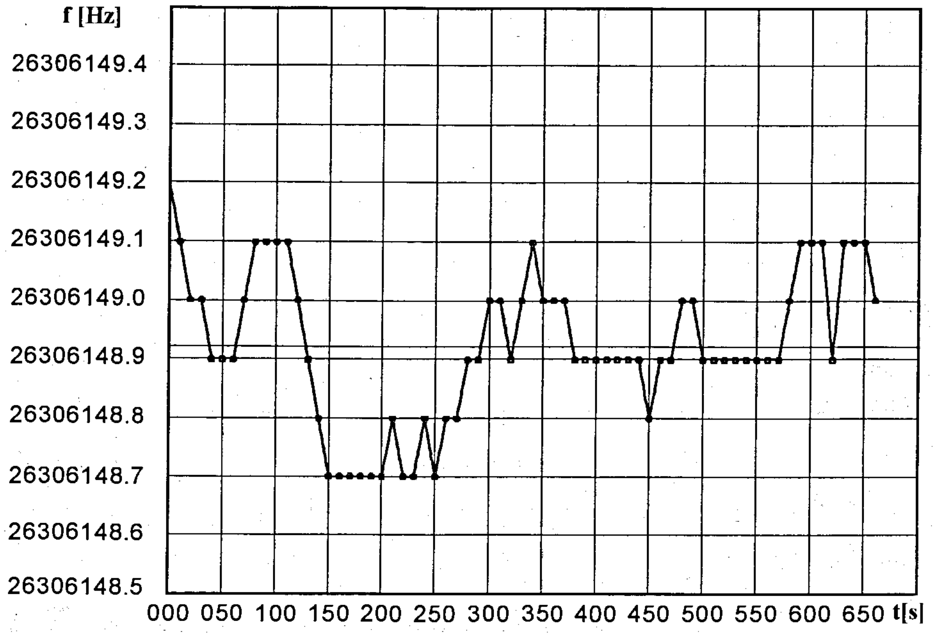

Fig. 4

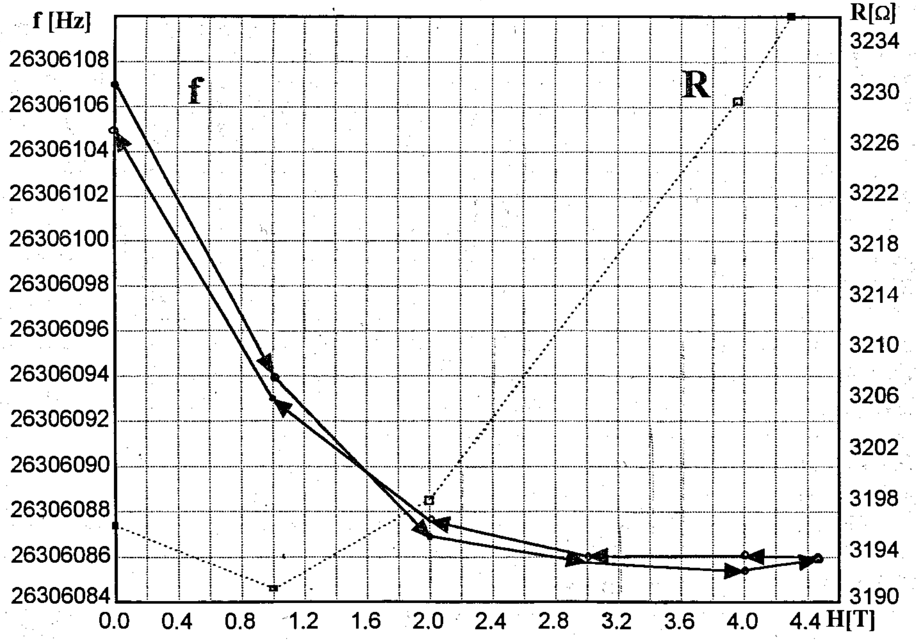

Fig. 5

detail its physical characteristics under the influence of low temperatures. This is the subject of collaborative activities during a few following years at the Acoustoelectronics Laboratory, ISSP, BAS and the Laboratory of High Energies, JINR, Dubna, Russia.

5. Acknowledgements

The authors would like to thank A.D.Kovalenko, chief engineer of LHE for excellent opportunities and support given for carrying out the low temperature investigations, as well as senior researcher Dr.I.Tsakov from the INRNE, BAS for many useful and enlightening conversations regarding this work.

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Received by Publishing Department
on August 26, 1996.