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Low-induction integral heater for temperature control of MEMS vapor cell

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Abstract. This paper describes a solution to the problem of temperature control and the occurrence of a magnetic field created by a resistive heater in a gas cell of an atomic clock. A low-induction integral heater was developed in the form of a two-layer metallization system that mutually compensates for each other's magnetic fields. Numerical simulation was carried out, based on the results of which a prototype of a low-induction integral heater was developed using precision photolithography and technologies for applying thin-film conductive and dielectric coatings. Static and dynamic tests of the fabricated integral heater were carried out.

Keywords: integral heater, MEMS, vapor cell

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Материалы конференции
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Малоиндукционный интегральный нагреватель для термостатирования МЭМС газовой ячейки

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Аннотация. В данной работе описано решение проблемы термостатирования и возникновения магнитного поля, созданного резистивным нагревателем, в газовой ячейке атомных часов. Был разработан малоиндукционный интегральный нагреватель в виде двухслойной системы металлизации, которая взаимно компенсирует магнитные поля друг друга. Было проведено численное моделирование, по результатам которого был разработан прототип малоиндукционного интегрального нагревателя с применением прецензионой фотолитографии и технологий нанесения тонкоплёночных проводящих и диэлектрических покрытий. Были проведены статические и динамические испытания полученного интегрального нагревателя.

Ключевые слова: интегральный нагреватель, МЭМС, газовая ячейка

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Introduction

Atomic frequency standards based on the absorption of alkali metal vapors (Cs or Rb) are the most precision standards of frequency and time. The development of microelectronics and microsystem technology provides technical opportunities for their integrated production, miniaturization, reduction of power consumption and cost. These devices include a cell in the form of a sealed capsule filled with alkali metal vapors. However, the disadvantage of reducing the overall sizes of the atomic clock cell is a decrease in the optical path, and therefore a decrease in the intensity of the output signal. An increase in the temperature of alkali metal vapors (80–200 °C), leading to an increase in the atomic density of vapors, is a key aspect of increasing the intensity of the output signal [1]. In addition, thermal stabilization has a high value, since temperature fluctuations can lead to changes in atomic density, relaxation rate and polarization [2]. Thus, the system of temperature setting and controlling is one of the key components of the atomic clock system.

Typical power for atomic clock cells is approximately 1 mW – 50 W, depending on the size and materials of the cell, as well as the casing [3, 4]. However, the use of typical resistive heaters leads to the formation of a parasitic magnetic flux density, due to the flowing current of the heater. The use of traditional heaters is impossible due to the extreme sensitivity of atomic cells to magnetic flux.

One of the ways to create a non-inductive heating and thermal stabilization is the using of hot air flow [5]. This method of heating the vapor cell is non-magnetic and allows to achieve high heating power. But its application requires high power consumption and has a low integration ability. An alternative method is the sequential combination of two parallel resistive heaters in the form of meanders [2]. This arrangement leads to compensation of the magnetic flux density, which is generated by each heater. However, the distance between the metal lines is on the order of a millimeter and its reduction is necessary to enhance the effect of magnetic flux suppression [6].

This project is aimed at solving the problem of creating a low-induction integral heater and a resistive thermometer for atomic clock cells. The solution of the problem is based on the formation of a two-layer metallization system mutually compensating magnetic fields of each other. In the course of the work, numerical modeling methods will be used to optimize the thermal stabilization system and the following production of prototypes using thin-film conductive and dielectric coating technologies and will be used precision photolithography.

Experimental

Before manufacturing the integral heater, numerical simulation was carried out in the COMSOL Multiphysics software. The purpose of the numerical simulation was to determine the configuration of the parasitic magnetic field and minimize it. The results of numerical simulation (Fig. 1) showed the possibility of reducing the magnetic field density to 10^{-12} T. Based on the obtained results, the construction of the integral low-induction integral heater was designed and produced.

The integral heater and thermistor are a two-layer metallization of chromium, made in the form of meanders (Fig. 2, *a*). SiO_2 was chosen as the insulation between the layers. The heater is made in the form of two turns of metallization with a width of 150 microns, and the thermometer in the form of six turns with a width of 30 microns.

The heater and thermistor were made by magnetron sputtering of Cr and SiO_2 layers on a LK-5 type glass substrate. The thickness of the metallization layer and the SiO_2 insulation layer was 100 nm and 400 nm, respectively. The resistances of the manufactured heater and thermistor under normal conditions are 280 ohms and 13.5 kOhms, respectively.

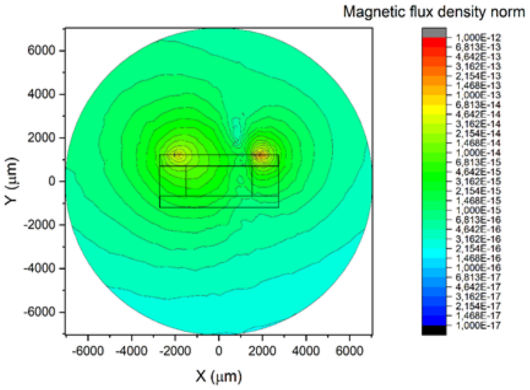


Fig. 1. Results of numerical simulation of the magnetic field density distribution

A fabricated low-induction integral heater was placed at the bottom of the vapor cell. The temperature of the vapor cell was controlled by an additional platinum microthermometer mounted on top of it. The resulting assembly was mounted on a ceramic suspension to reduce heat leakage. The ceramic suspension was made by laser scribing. Figure 2, *b* shows a schematic diagram of the resulting test block. Static and dynamic tests were carried out to determine the properties of the integral heater and thermistor.

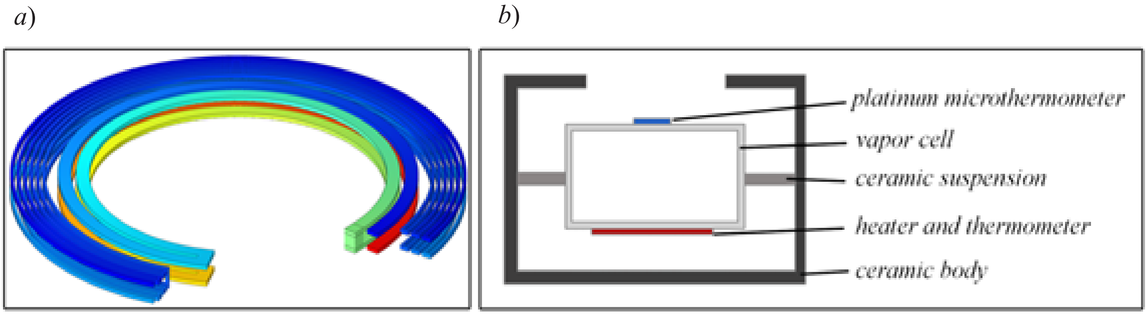


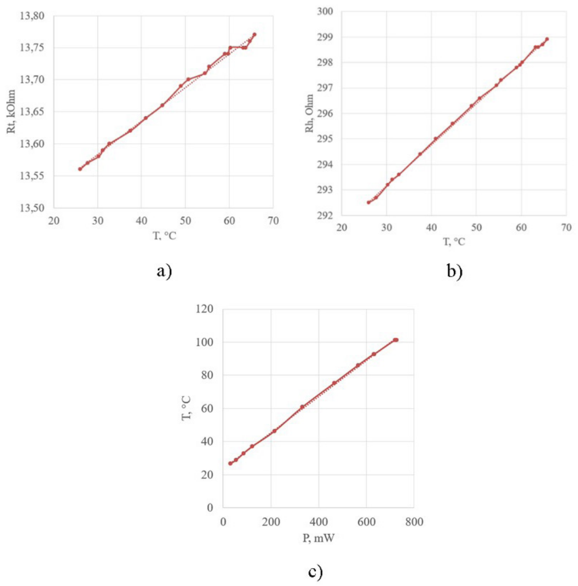
Fig. 2. Double-layer heater and thermistor (*a*); schematic diagram of test block (*b*)

During the static tests, the test block was placed on the hot plate. After reaching thermal equilibrium between the hotplate and the test block, the heating was turned off. As it cooled down, the resistances of the heater and the thermistor were measured. The determination of the temperature of the vapor cell was determined using a platinum microthermometer.

For dynamic tests were assembled a measuring circuits for a heater, a thermistor and a platinum microthermometer. A signal was applied to the thermistor and platinum microthermometer using the generator AKIP series AKIP-3409/2 (China). A voltage was applied to the heater using the power supply QJE series QJ3005P (China). Turning off the heating led to a change in the signals that were transmitted to the thermistor and the platinum microthermometer. power supply. The signal was measured using the digital oscilloscope AKIP series AKIP-4109/2 (China). The time constant for the thermistor and the heating time of the heater were determined by changes in the signal.

Results

During static tests the dependences of the resistance of the heater and the thermistor on the temperature were determined (Fig. 3, *a*, *b*). The temperature dependence on the heating power was also determined (Fig. 3, *c*). Due to the linear dependence of the resistances on temperature, the integrated heater can easily provide thermal stabilization up to 100 °C at a heating power of 700 mW. As part of the dynamic tests, the time constant for the thermistor and the heating time of the heater were obtained. The time constant of the thermistor is 800 ms, and the time of the heater is 20 ms. The results of dynamic tests show that the integrated heater has a high level of response time.



a)

b)

c)

Fig. 3. A graph of the dependence of the resistance of the thermistor on the temperature (*a*); a graph of the dependence of the resistance of the heater on the temperature (*b*); graph of the dependence of the temperature on the heating power (*c*)

Conclusion

The characteristics of an integral heater and a thermistor were studied. The manufactured integral heater has the possibility of thermal stabilization up to 100 °C at a heating power of 700 mW.

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