Creation of a flexible thin-film thermoelectric converter for the range -50...150 degrees Celsius

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Abstract. The paper presents the results of a project to create highly sensitive thermoelectric converters for small temperature differences on a flexible film base, consisting of a large number of compact thermocouples connected in series. Such sensors may be used, for example, as the part of fire alarm systems without any power supply. The sensors were produced as multilayer structure coating of thermoelectric alloys on the flexible polymer substrate through photolithographic masks. A pair of chromel-T and kopen was taken as thermoelectric alloys. The preliminary operating parameters of the obtained samples are presented.

1. Introduction
Differential temperature sensors are used everywhere, including fire or coolant leakage warning systems. However, in the range of low temperatures (-50…150°C) measurements via passive sensors are difficult. The smaller the temperature difference, the greater the measurement error, the more accurate and expensive equipment is required to interpret the signal received from the sensor. For this reason, thermal resistances are more often used for this temperature range, but their operation requires additional power supplies [1]. A multiple increase in the specific thermoelectromotive force of a passive thermal sensor would make it possible to significantly simplify and reduce the cost of measuring temperature differences in the specified range.

Vacuum-plasma technologies make it possible to create compact and efficient electronic components, including sensitive elements with a much higher output signal level without a significant increase in price, dimensions, weight and material consumption relative to existing passive thermal sensors.

The aim of the work was to develop technology, manufacture and confirm the operability of prototypes of thin-film thermoelectric converters.

2. Materials and Methods
The manufacturing technology of thin film multilayer thermoelectric converters is based on the method of magnetron sputtering [2, 3] of thermoelectric alloys to form the two-layer coating on a polymer substrate. This method makes it possible to form thin films of metals, including alloys, with almost no change in their composition.

Before deposition, the substrate was cleaned with ion beam produced by anode layer accelerator. The exposure and energy of the ion beam were selected to provide the mask retention. The thickness of
the deposited layers was 280 nm, since it is difficult to remove the photoresist with the layer thickness more than 300 nm. Chromel-T and kopel alloys were chosen due to the combination of their high specific thermopower and manufacturability. A polyimide film was used as the substrate material, since the substrate required mechanical strength, heat resistance, solvent resistance, and minimal shrinkage upon heating.

The best way to arrange the maximum number of junctions pairs per unit area and separate the areas of hot and cold junctions is a meander pattern. This pattern was created from two layers of alloys, providing an overlap between the layers in the hot and cold side junction areas. Conventional photolithography, based on chemical etching of the required pattern on a continuous metallization layer, is not suitable for a two-layer element due to damage of the lower deposited layer during the etching the upper one. Therefore, the method of templateless reverse photolithography [4, 5] was chosen, and it was used twice for successive deposition of chromel-T and kopel films. The photolithography method required a reliable fixation of the film on a solid base, which was a silicon wafer. Two methods were considered: the deposition of liquid polyimide on a tungsten sublayer and the application of a polyimide film with an adhesive layer on a solid silicon wafer. The first method supposed the chemical deposition of polyimide film on a silicon wafer with tungsten sublayer coating. After the process the tungsten sublayer was chemically dissolved but polyimide film was damaged during the process. So, it was decided to use a ready-made film 20 µm thick with an adhesive layer fixed uniformly and without defects as the base for metal thin film coatings on a silicon substrate. The magnetron sputtering was used as the coating method.

3. Results
A number of flexible sensitive elements with dimensions of 20x24 mm on a polyimide base were obtained. The resolution of the structures in the experimental batch ranged from 1 mm to 50 μm (Figure 1). The calculated resistances of such elements are from 0.95 to 91.7 kOhm, the calculated specific thermoelectromotive force is from 0.68 to 6.57 mV/K. The dimensions of the elements and the resolution of the structures are determined by the equipment used for photolithography.

Flexible polyimide base was fixed on a silicon wafer with the adhesive. The film was taken off by various methods, but the separation with heating of silicon wafer showed the best result. However, some samples were damaged and lost their conductivity. The elements before separation from the silicon wafer are shown in Figure 1.

![Figure 1. Thin-film thermoelectric sensors on a silicon wafer](image)

As a result, prototypes of sensitive elements were obtained with a resolution of 0.5 mm and 0.3 mm with the number of junction pairs 11 to 18 respectively. The resistance was from 1.4 kOhm to 7.8 kOhm. The elements produced thermoelectromotive force when the “hot” junctions were heated up to
ΔT 100 degrees, ranging was 0.57 and 0.93 mV/K, which in terms of a pair of junctions corresponds to 52 μV/K.

4. Discussion
Theoretical resistance values of operable samples range from 0.95 and 2.59 kOhm for a track width of 0.5 mm and 0.3 mm, respectively. The actual resistance values are 1.5…3 times higher than the calculated values. Such a significant difference is most likely associated with the appearance of microcracks during the separation of the samples from the solid substrate.

The theoretical values of the specific thermoelectromotive force of operable samples range from 0.68 mV/K to 1.12 mV/K at the rate of 62 μV/K from one pair of junctions. The lower value of the actual specific thermoelectromotive force in comparison with the theoretical values is presumably due to the change in the stoichiometric compositions of the alloys during magnetron deposition on the substrate. It is also possible that chemical contamination of the junction areas may take place during the masking process.

The work performed has shown the operability of the method to obtain thin-film thermoelectric converters with layer-by-layer magnetron sputtering technology on a polymer substrate. The obtained samples showed an average specific thermoelectromotive force in terms of a junction pair of 52 μV/K, which is close to the theoretical value of 62 μV/K.

However, a serious technological problem was the separation of the finished samples from the solid base required for applying masks by photolithography. The solution of this problem will make it possible to obtain operable samples with a resolution of 50 μm with a thermoelectromotive force of the element up to 6.57 mV/K, which at a temperature difference of 100 K corresponds to a generated voltage of 0.66 V.

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