Ročník 2012 electroscope Číslo VI

Design and Fabrication of MEMS Low Power Heating Membrane

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Abstract:
The aim of this work is design and fabrication of micro hotplates. This type of device is often used for gas-sensing applications. The main goal is to produce the structure of the heating membrane using different fabrication process. Only wet etching process is used. Mainly two types of membranes are discussed – suspended and close type of the membrane. The sample which is going to be produced will be a membrane with the size of 1×1 mm, to ensure a suitable fabrication technology and the applicable design of the micro hotplate. The micro hotplates power consumption has to be up to 100 mW at the operating temperature 480 °C.

INTRODUCTION

Micro hotplates have a tremendous importance in the field of high temperature gas-sensing devices since they allow the reduction of sensor power consumption and the use of new modes of operations such as temperature cycling due their low thermal mass [1][2].

The fabrication process includes micromaching: deposition of thin layers, photolithography, and etching to create close or suspended type of the membrane (Figure 1). The heater will be probably produced using Au as the heating electrode. Metal film hotplate offers precise temperature control, which can be also used as a thermometer; it simplifies the device structure [3][4]. Many designs of heating electrode are discussed but most probably the meander or similar design will be used for heating the micro hotplate.

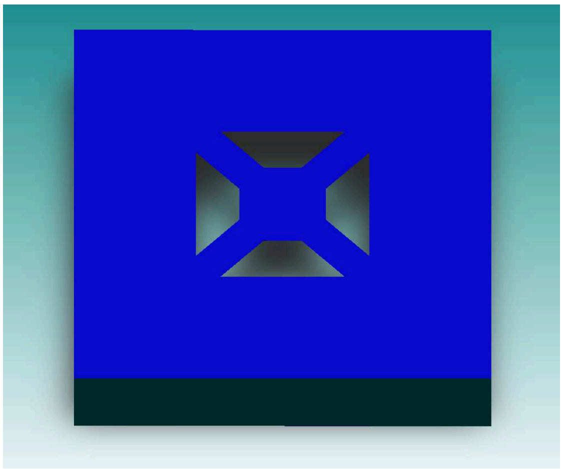

Fig. 1: Model 3D suspended structure of membrane

DESIGN

Design has been supported using mechanical and thermal simulation in ConvertorWare software (Figure 3). The most important and fundamental parameters during design of micro hotplates are power consumption, operating temperature and robustness of the structure (Figure 2).

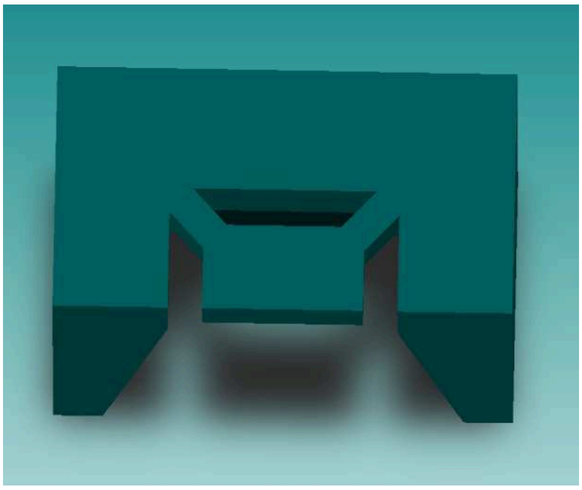

Fig. 2: Cross section view of suspended membrane

The first samples were fabricated using just silicon wafer with thermal oxide, so the membrane itself were made on the silicon. There was observed low stress caused by increasing of temperature but the power consumption was over 100 mW due to thermal conductivity of silicon. Therefore, LPCVD silicon nitride was used in latter designs. LPCVD silicon nitride provides good properties for micro hotplates, low thermal stress, robustness and lower value of the thermal conductivity which helps to achieve the lower power consumption.

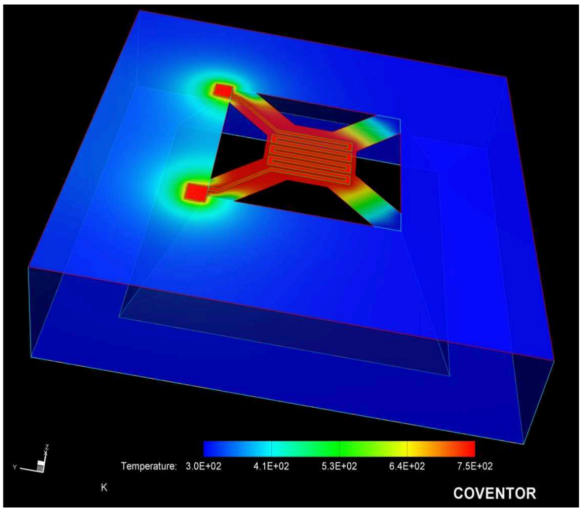

Fig. 3: Graphic results of thermal simulation CoventorWare

There are three main factors of the total thermal loss: first, thermal loss due to conduction; second, a loss in the surrounding air due to the thermal convection, size (thickness, membrane length and active area dimension), the specific thermal conductivity of the membrane material, silicon nitride in these experiments, and finally the loss due to radiation [5].
Thermal simulation in the ConventorWare software was used to observe behavior micro hotplate at the operation temperature. Graphical results show the heating electrode causes homogeneous distribution of temperature (Figure 4 and 5).

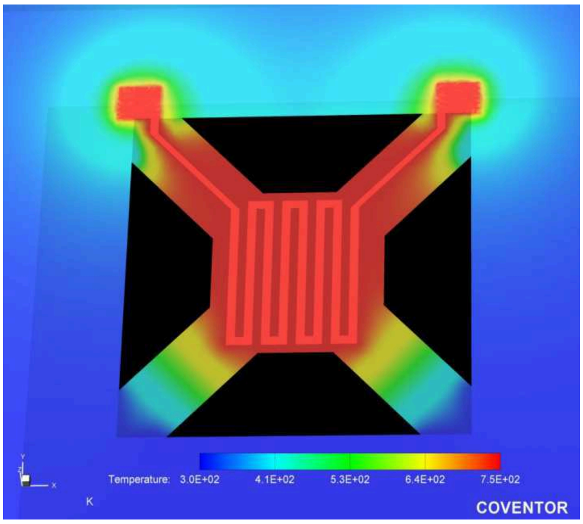

Fig. 4: Graphic results – Top view of micro hotplate

The used type of beams causes the bending of structure up and down, when the temperature is increasing to the operating point of the device. The orthogonal beams cause more the turning hotplate, then bending this structure up and down. This effect may help to decrease the stress of the micro hotplate. In this stage of experiments there are many types and new designs investigated.

The size of the designed membrane was from 0.5 to 1.0 mm. The beams of the suspended membrane were 100 to 150 µm wide. The thickness of membrane and its beams (suspended type) is design to be 250 nm, so it is very important to count with thermal stress and robustness of the final device.

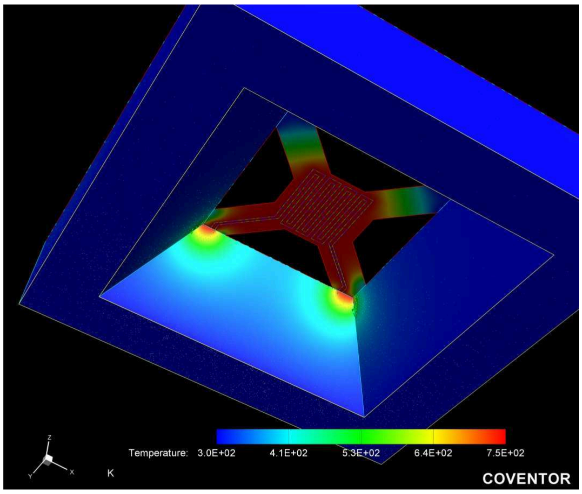

Fig. 5: Graphic results - Bottom view of heating plate

FABRICATION

The standard fabrication process was as follows. The starting material was a (100) one side polished silicon wafer with thickness of 500 µm. A thermal oxide of 1.1 µm was grown both sides. The first step was to create top structure of the suspended membrane then backside etching to release the membrane in the second step. The structure of the micro hotplate was created in the layer of silicon dioxide using solution of HF and CH3COOH. In this case the photoresist was used as the protective mask during etching. The silicon dioxide was used to create the top structure of the micro hotplate during etching, as well as this layer was used to the backside protection during wet chemical etching in KOH (30%, 80°C). The top structure was etched 30 µm deep in the silicon wafer.
The second step was to release the membrane by wet chemical etching using the same solution of KOH. The sample was laid down on the piece of polymer which can dismiss the vapors of KOH to etch just the back side of the wafer. Time of realizing membrane was about 12 hours. Etching of this step caused the partial destructions of the top structure.
In this stage of experiments it is necessary to find a more optimal protective mask for the etching process (e.g. silicon nitride). When the structure of the membrane is optimal (robustness, thermal losses), the heater is fabricated. The gold electrode will be used as heating electrode.

RESULTS AND DISCUSSION

The structure of the suspended membrane was created by using wet chemical etching but the final structure prepared for a heating electrode is not completely suitable for final devices. The structure of the micro hotplate is partly damaged because of etching process, and due to the imperfect mask used during lithography. With respect to these conditions, there could be an unexpected behavior while the temperature will be increasing. This structure is not suitable for devices working in impulse mode as well. One beam of the hot plate is thinner due to previously mentioned reasons as shown in Figure 6.

During backside etching of silicon substrate most of destruction was done. When hotplate was nearly realized, the windows of suspended membrane were not opened at the same time, therefore vapors of KOH started to etch individual beams.

There is need to improve the reproducible fabrication process.

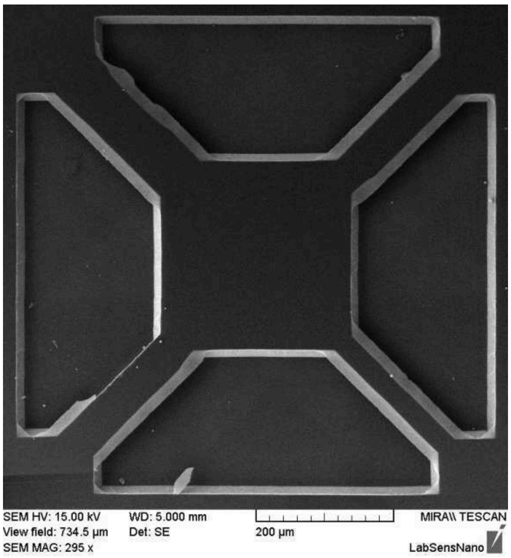

Fig. 6: SEM picture of fabricated suspended structure

The improvement could be reached by making the beams orthogonal to the hotplate. This step may cause a smaller rate of etching beams in that direction.

All experiments which have been done since beginning of experiments, used silicon oxide as protective mask for etching. Better results are expected with LPCVD silicon nitride.

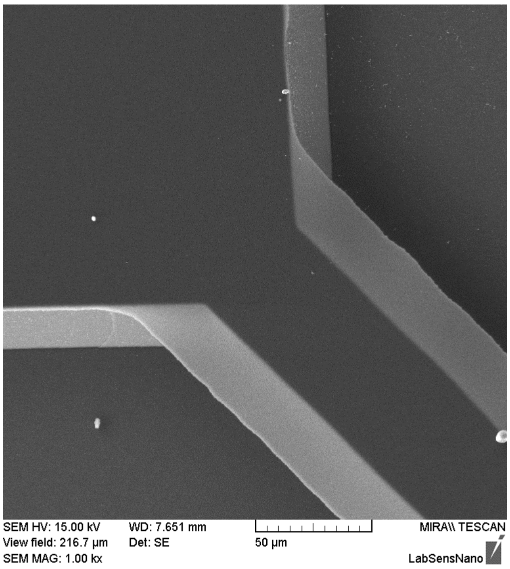

Fig. 7: SEM picture - Detail view of supportive beam

CONCLUSION

Design and fabrication of micro hotplates have been described many times over the literature, but improving design and fabrication is still needed to reach as minimum power consumption as possible, therefore the membrane and hotplate structure have to be investigated. This paper reports on the other techniques which are not used so much for fabrication of this kind of structures. The structures of membrane have never been made just by using wet etching processes. It is very important to investigate these possibilities of micro hotplates fabrication because there is always a need to decrease power consumption of these devices and improve their robustness for intended applications.

ACKNOWLEDGEMENT

The financial support from the grant GAČR 102/08/1546 and project SIX CZ.1.05/2.1.00/03.0072 is highly acknowledged.

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