Thin-film thermal converter as ac/dc transfer standard

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Summary: Thermal converters are the most accurate devices used by National Metrology Institutes for the transfer of ac voltage and current to equivalent dc quantities. Design, simulation and microfabrication of a thin film thermal converter on a silicon chip is presented, for a frequency range from 10 Hz up to 1 MHz. Surface and bulk micromachining were done over (100) Si wafer. A nitride membrane, 8000 Å thick, acts as support for the NiCr heater. Four sensing resistors are made of VO$_2$. Photolithography, sputtering and wet etching processes are involved. Packaging of the microsystem will be performed on low temperature co-fired ceramic.

Introduction

Thin film thermal converters with thermocouples as temperature sensing devices have been extensively studied [1, 2]. They are currently used as AC-DC transfer national standards in most of the NMIs and also in secondary calibration labs. Resistive sensing was also used in the past in classical wire thermal converters [3]. A thin film thermal converter was also introduced with aluminium as material for the sensing resistor and a feedback circuit to allow isothermal operation and fast response [4]. We used vanadium oxide (VO$_2$) as material for the sensing resistor. It has a high temperature coefficient of resistivity (TCR) allowing a high sensitivity of the device.

Basic design

Figure 1 shows the basic design of the device. A bifilar NiCr heater is used, four VO$_2$ resistors are sputtered on the membrane, two of them near the heater (R1 and R4) and two of them on the silicon frame (R2 and R3). When a voltage (or current) is applied to the heater R1 and R4 are heated and R2 and R3 remain at ambient temperature. The four resistors are connected in a Wheatstone bridge configuration. Figure 2 shows the Wheatstone bridge used to measure the changes of the resistances. The voltage source of the bridge is 2 V.

Microfabrication Process

Surface and bulk micromachining were done over four inches (100) Si wafers, double side polished. We choose Si with volumetric resistivity lower than 10$^{-2}$ cm to reduce ac-dc difference at high frequency [5]. A low stress Si$_3$N$_4$ layer is on both sides. Nitride thickness is in the order of 8000 Å, obtained by LPCVD. This nitride layer works as mask for Si wet etching, and as a membrane for structural support.

Isopropanol standard cleaning was applied. Four photolithographic processes were needed to complete the device, mask designs are shown in figure 3. A double side EVG620 mask aligner was used. Three Surface micromachining at sop side of the wafer were performed by lift off technique. Positive photoresin AZ9260C 3027 was spin coated with a thickness of 5.7 µm. During UV exposure 140mJ/cm$^2$ were applied.

A Boc Edwards Auto 500 physical vapour deposition system, DC / RF sputtering, was used to deposit the three active layers. For the heater we selected a NiCr alloy target (80/20 wt%). For 50 nm deposition, 200 W RF sputtering was necessary during 33 min. Contacts were made of Aluminium, at 400 W during 40 min.

Cavity at the back side was performed completely by wet chemical etching. HF and phosphoric acid were used to open nitride area, Ti 35E image reversal photoresine was used on negative mode. Silicon wet etching was performed by KOH 40% solution during 10 hours.

Figure 1: Side and Top view of thermal converter design chip. At left, Wheatstone bridge configuration

Results

Preliminary results are shown on figure 6. Temperature characterization was performed on a PML8000 Wentworth Lab probe station and 4200SCS Keithley Parametric Analyzer. The resistance of vanadium oxide was in the order of 4 kΩ. Evaluation was performed between 25 to 250°C, resulting in a variation from 40 to 20 kΩ.

Conclusions

Design and microfabrication was successfully performed. Double side alignment was realized according to expected results, besides alignment marks should be reconsidered to facilitate procedure. Nickel and vanadium dioxide is still under characterization.

References