1. Introduction

The detection and measurement of humidity are very important in environmental fields such as medical or domestic applications for human comfort[1]. Humidity sensors are based on various principles: quartz oscillator[2-4], macromolecular sensors[1,2,5], electrolyte[1,2], semi-conductors[2,6,7], porous materials: ceramics[1,2] and silicon[8].

With increasing interest in thin film thermoelectric devices, we have studied a thin film humidity sensor based on the Seebeck effect[9]. This phenomenon is due to the creation of an electromotive force in a conducting material subjected to a temperature gradient. In previous work[10] the development and characterization of micro-module Peltier (MMP) elaborated by a flash technique have been studied. The MMP is a P-N junction realised by a deposition of (Bi$_2$Te$_3$-Bi$_2$Se$_3$) alloys for N type materials and (Bi$_2$Te$_3$-Sb$_2$Te$_3$) alloys for P type materials on polyimide substrate. In order to investigate the performance of our flash evaporated layers, we tested three different structures of MMP, and with these first results we optimised in this work a “butterfly” MMP structure (B-MMP) that we used as a humidity sensor.

2. Optimisation of the MMP structure

With the results obtained on the three previous MMP we have realised a new MMP structure. This structure which we have called “butterfly” (B-MMP) is represented in Figure 1 and more details are given in Table I. The B-MMP structure is designed to resolve some of the disadvantages of the previous MMP:

- stabilisation of the temperature reference;
- reduced contacts resistance;
- reduction of the Joule effect;
- augmentation of the temperature difference between the cold side and the hot side.

The thermal gradient is improved by the geometrical modification of the MMP structure which gives to the Peltier effect[11]
an advantage over the Joule effect. Indeed, current density of the B-MMP structure is decreased by the use of thin P and N layers; therefore the Joule effect is also reduced.

Moreover, the Peltier effect increases on the thermal-electrical shunt because of the increase in the current density. With this B-MMP structure a temperature difference between the hot and cold side of 9.5°C is achieved for an injected cooling current (Ip) of 50mA as shown in Figure 2.

3. Measurement principle

A humidity sensor is constructed using this B-MMP structure. The measurement principle is described below:

- Water condensation is produced by Peltier effect applied on the P-N junction;
- After stopping the Peltier cooling, the evaporation is detected by the structure when used as a simple thermocouple (Seebeck effect).

In fact, the flash elaborated B-MMP also produces a very high thermoelectrical sensitivity of 440 µV/°C allowing the temperature variations specifically related to evaporation to be followed.

This sensor was characterized in a climatic chamber SECASI controlled by SIRPAC software and using Labview software.

4. Experimental measurements

Experimental measurements are achieved in a climatic chamber for several values of relative humidity from 50 to 95 per cent and for a B-MMP current Ip = 40mA. The temperature was maintained constant and equal to 20°C; no temperature compensation was necessary.

The experimental measurement apparatus is shown in Figure 3. To verify that our results

| Table I Thermoelectric and geometrical characteristics of each MMP structure |
|------------------|------------------|------------------|------------------|------------------|
|                   | MMP1             | MMP3             | MMP4             | B-MMP            |
| e(µm) thickness of active layers | 20               | 20               | 20               | 20               |
| L (µm) length of active N or P layer | 100              | 500              | 1,000            | 300              |
| ρ (µΩ.m) experimental resistivity of P type layer | 12               | 12               | 12               | 12               |
| ρ (µΩ.m) experimental resistivity of N type layer | 15               | 15               | 15               | 15               |
| RC (Ω) contact resistance (Ω) | 2.75             | 3.57             | 9.92             | 0.52             |
| α (µV.K⁻¹) experimental Seebeck coefficient of N type layer | 200              | 200              | 200              | 200              |
| α (µV.K⁻¹) experimental Seebeck coefficient of P type layer | 240              | 240              | 240              | 240              |
are repeatable we use the Peltier reversibility effect to pre-heat the water detection zone for 4 seconds by applying a heating current $I_h = 40\,\text{mA}$, then we reverse the current to apply $I_p = 40\,\text{mA}$ for 4 seconds. The analysis of the Seebeck voltage supplied by the thermocouple begins only at the end of the $I_p$ injection.

Figure 4 shows the current injection process and the Seebeck voltage obtained as a function of time for a humidity of 70 per cent. We think that the steep decrease in the Seebeck voltage observed on this curve correlates with when water evaporation occurs. In Figure 5 we show the measure of this delay time, $\tau$, versus different humidity levels. The higher the humidity level, the longer is time $\tau$. The experimental conditions are described as follows:

- heating current $I_h = 40\,\text{mA}$, heating time $T_h = 4\,\text{s}$;
- cooling current $I_p = 40\,\text{mA}$, cooling time $T_c = 4\,\text{s}$;
- ambient temperature 20°C.

We have presented here the first results of this structure used as a humidity sensor. The delay time $\tau$ of the Seebeck voltage decreases rapidly with humidity (Figure 6). Then it is possible to draw the evaporation delay time as a function of relative humidity.
5. Conclusion

In this work we have shown how, with the optimisation of contact and experimental resistance for the MMP structure (B-MMP), we obtained a maximum value for the temperature drop between hot and cold sides of about 9.5K. So we used this B-MMP structure as a humidity sensor for high humidity levels. These first results, coupled with those obtained in our laboratory by Pascal-Delannoy et al. [12], are very promising and offer a very wide domain of possible applications in the sensors field.

References