MICRO SYSTEM ARRAY SENSORS

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Abstract

Array sensors are presented as sensors, which take full benefit of integration of many functions into micro systems and are designed using the expertise of many disciplines. A description of various different applications of array sensors is given. Two examples, the extraction of multiple physical parameters and chemical parameters, are given. As physical parameter, the indirect determination of the density of a gas is carried out by combination of two measurement principles for the gas flow. In the chemical domain, measurement of reaction products of a sample gas, catalytically converted by a micro actuator, provides information about the composition of the gas. Both systems make use of the same IC-compatible technology.

Introduction

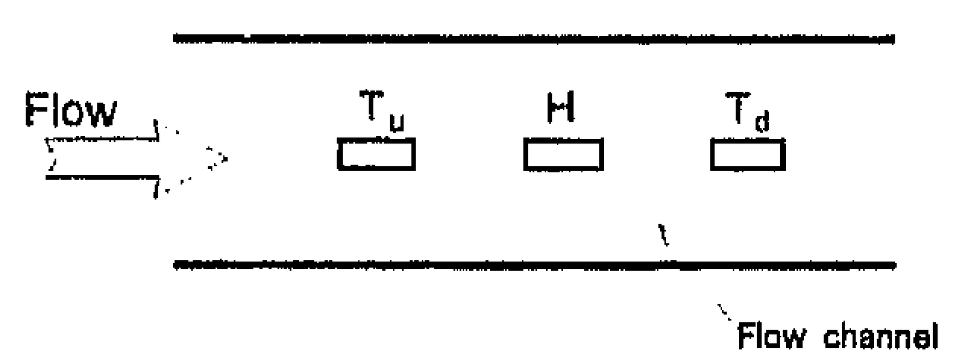
Array sensors can have a variety of different functions. They can be used to give a spatial mapping of one particular parameter, to determine a large number of different parameters, to increase the system's selectivity or accuracy by over sampling, or, in combination with pattern recognition techniques, to recognise properties of a sample that cannot be determined directly. Examples of the first function, spatial mapping, are the well-known CCD photodiode array present in many video camera's, thermal [1] and tactile sensing [2,3], but also electrochemical electrode arrays used for mapping of biochemical parameters and processes [4]. The second function, determination of multiple parameters, is illustrated by an ISFET array sensitive to pH, potassium and calcium [5], whereas an increase of the sensors selectivity and pattern recognition [6] as well as indirect measurement of a gas by detection of its combustion products [6,7] have been demonstrated with gas sensors.

In order to have an optimal performance of the sensor array, it should be incorporated in a miniaturised measurement system. The recent upcoming of micro system technology offers many techniques to realise such micro measurement systems by integration of sensor array with actuators and fluid handling elements. The thus realised micro system offers new and interesting opportunities. Of course the big challenge is to realise all system elements using one technology.

Two examples of micro system array sensors will be presented: an array gas flow sensor for determining physical gas parameters and a catalytic gas sensor array for determination of chemical gas compositions. The first example involves the indirect extraction of gas properties that cannot be determined directly. Gas density is difficult to determine with a direct measurement. However, a combination of two other determinations, e.g. the simultaneously mass flow and volume flow, the wanted gas density can be extracted from the output data generated by the array sensor components.

Array gas flow sensor

In this array sensor the gas to be measured is led along two different types of flow sensors. Each flow sensor generates an output signal which is related to a combination of physical parameters of the passing gas. One type of flow sensor is the well known anemometer type with three (metal) resistors crossing the flow channel (see Figure 1,a) [8]. The middle resistor (H) is heated with a constant power and the resulting (steady state) temperature distribution in the flow channel is measured at two points with the additional sensing resistors T_u and T_d. With zero gas flow, the temperature profile is symmetrical and the temperature difference between T_u and T_d is also zero (see Figure 1,b). At a certain flow rates, the temperature difference reaches a maximum and at higher flow rates it tends to lower again. With negative flow, the temperature difference will also change its sign.



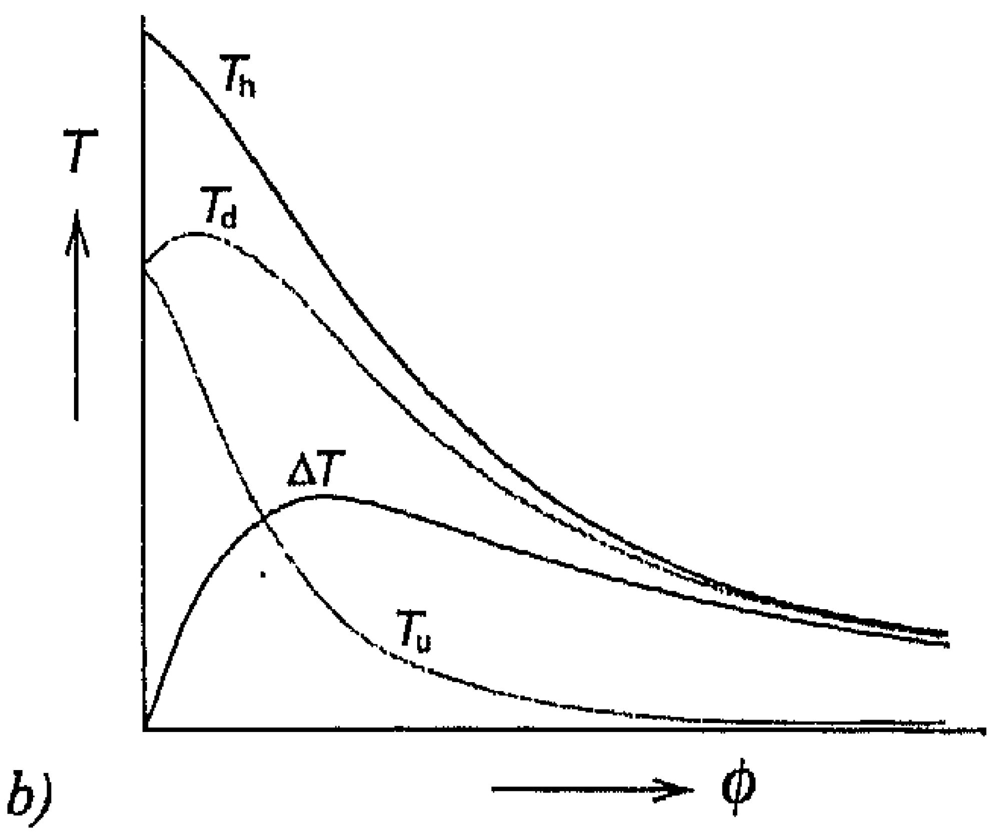


Figure 1. a) Cross section of flow sensor with three resistors in the middle of the flow channel. H is the heater, T_u the temperature sensing resistors flow upwards and T_d the temperature sensing resistor flow downwards. b) Temperature of the different resistors as function of the flow. The sensor signal is $\Delta T = T_d - T_u$.

The same flow is also led through a 'time of flight' type flow sensor with two (metal) resistors (see Figure 2a). The first resistor (H) is heated with a current pulse and the resulting (dynamic) temperature is measured with a temperature sensing resistor which is located downstream (T_d). The heat transport mechanism is due to diffusion and to convection. The resulting temperature (and output signal) at T_d is a function of time and flow (see Figure 2.b). The time span between the generating the heat pulse and the point in time at which a maximum (dynamic) temperature at T_d is reached (t_m) is related to the fluid flow (see Figure 2.c).

Because both the sensor output signals relate on a different way to the physical gas parameters, the Helium content of an He/N_2 mixture can be calculated from both signals (see Figure 2.d) [9].

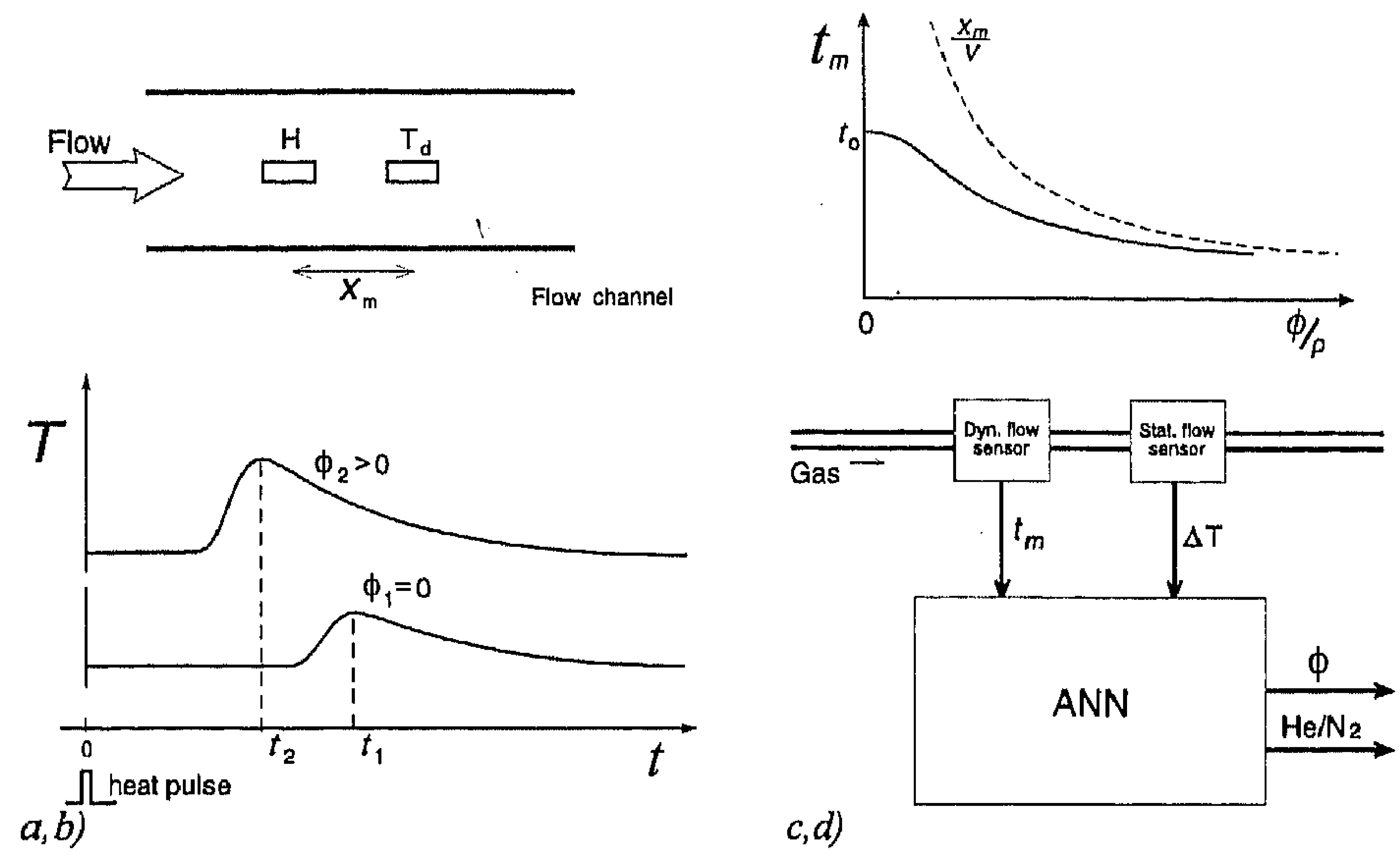


Figure 2. a) Cross section of sensor with two resistor elements; H is the heater and T_d is de downstream temperature sensor. b) Temperature as function of time for two gas flows. At t_1 and t_2 the (dynamic) temperature reaches its maximum. c) The time t_m as function of the gas flow. d) Two sensors signals are processed in an Artificial Neural Network (ANN) to calculate the He content of a He/N_2 mixture [9].

Technology

The sensors are realised on a <100> Si wafer (see Figure 3) covered with a SiN layer (1 um, 3.a). After patterning the SiN layer (3.b), the metal layer is deposited (sputtering or lift-off) and patterned (3.c). The flow channel is (anisotropically) etched in a KOH solution (70 °C) resulting in the typical cross section (3.d) which is 1000 um wide and 250 um deep. In the Pyrex wafer the flow channel is (isotropically) etched in a HF solution (3.e). Finally the Pyrex wafer and the Si wafer are anodically bonded (3.f).

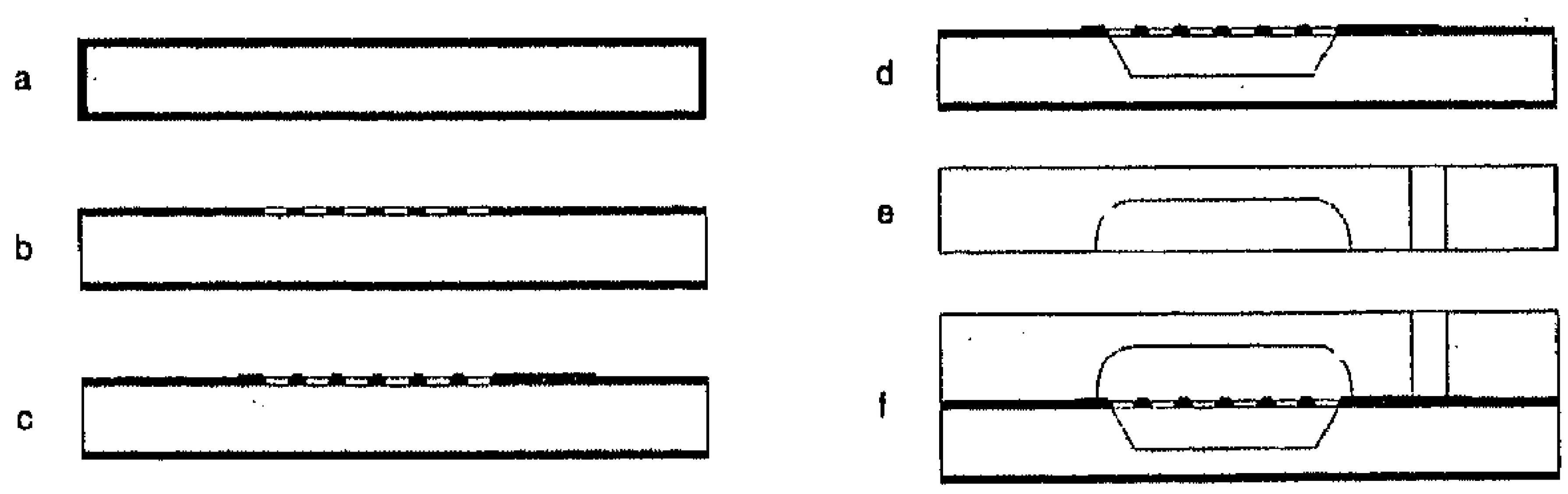


Figure 3. Process sequence for realising the metal resistor elements in a fluid channel. The process is fully compatible with CMOS IC-technology. Steps b-f are done after the realisation of eventually on-chip electronics.

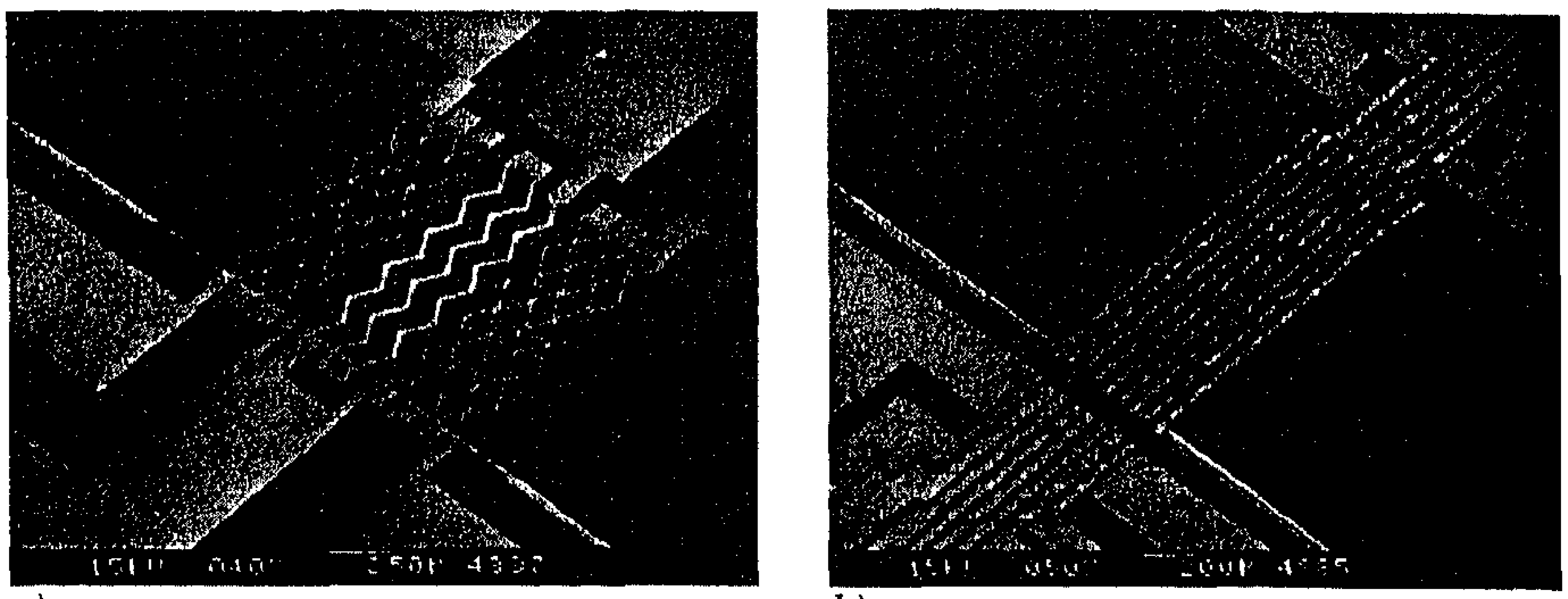


Figure 4. a) Anemometer type flow sensor [8]. b) One dimensional multifunctional sensor/actuator array with 9 metal film resistors above the etched flow channel. The width of the flow channel is 1000 μm, depth 250 μm and the element distance is 80 μm. The thickness of the metal film is 200 nm. De Si_3N_4 carrier bridges are 1 μm thick and 40 μm wide. Each element can be (dynamically) switched between the actuator function (dissipating) and the sensor function (temperature dependent resistivity).

Catalytic array sensor

With miniaturised catalytic sensors resistance variations in heated thin noble metal films as a result of the thermal effect of conversion of combustible gases is measured [10]. Since the reaction rate at the metal surface is a strong function of both temperature and type of metal [6], these intrinsically relatively non-selective sensors can be made more selective. Therefore, an array of 9 thermally isolated suspended bands of three different metals (M1-M3), which are held at three different temperatures (T1-T3) can be used to obtain 9 (poorly) selective sensor signals. The technology used for the fabrication of the device (see figure 6 and figure 5.b) is equal

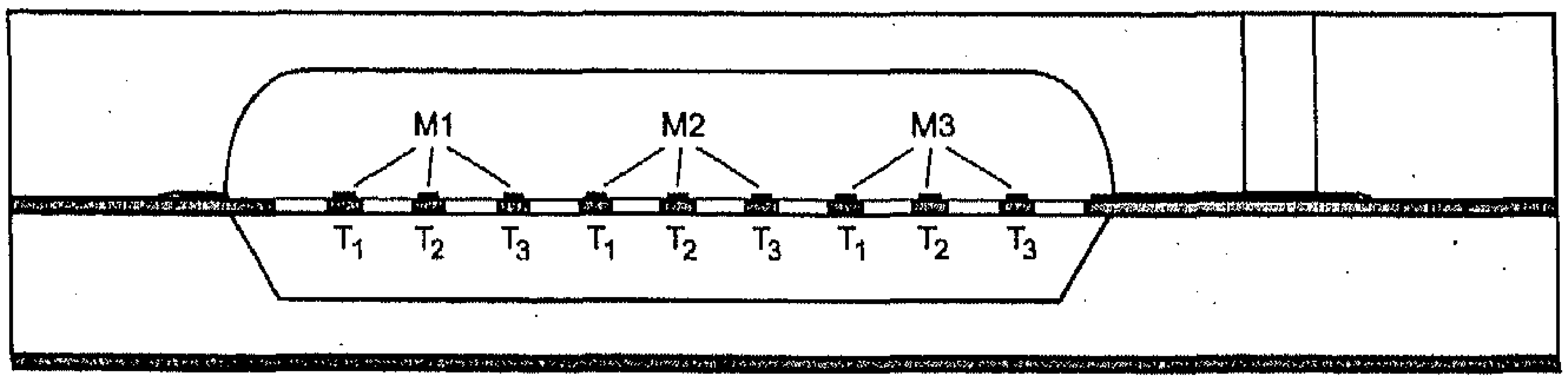


Figure 6. Cross-section of an array gas sensor with three different catalytic metals (M1-M3) and three different temperatures (T1-T3).

to the one earlier described, except for a threefold lift-off step for the deposition of the three different catalytic metals. By multicomponent analysis, the nine sensor signals can be combined to provide a selective determination of one or several components.

Alternatively, using an optimised design (with a much smaller channel height to assure rapid gas diffusion to the heaters and complete conversion) one or more of the downstream heaters can be used to combust the gas, whereas the upstream sensors can be used to analyse the combustion products.

One of the important advantages of micro structures for this type of sensors (arrays) and systems is the low power consumption as compared to conventional catalytic converters (pellistors). This allows the fabrication of relatively large arrays that cover a wide temperature range and still can be used for portable applications.

Conclusions

Two different functions of the array sensor are illustrated and discussed. An array flow sensor has been integrated combining two different sensors in one single realisation process. The proposed metal resistor elements are very simple to realise (2 mask process) and can be integrated straightforwardly with current micro electronics technology. On-line pattern recognition by an ANN (Artificial Neural Network) Application as sensing system for determining the Helium content of an Helium Nitrogen mixture is feasible. As second function, a catalytic gas sensor array for determination of chemical gas compositions is proposed. Both array sensors can be realised using the same technology.

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