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Realization of an integrated VDF/TrFE copolymer-on-silicon pyroelectric sensor

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An integrated pyroelectric sensor based on a vinylidene fluoride trifluoroethylene (VDF/TrFE) copolymer is presented. A silicon substrate that contains FET readout electronics is coated with the VDF/TrFE copolymer film using a spin-coating technique. On-chip poling of the copolymer has been applied using a step-wise poling at room temperature. The copolymer deposition and polarization are compatible with semiconductor technology. A 3x1 integrated pyroelectric sensor has been realized. Voltage sensitivity and noise of this sensor have been measured.

1. INTRODUCTION

Integrated single, linear-array or matrix pyroelectric sensors on silicon based on PVDF-technology were already developed in the late 1970's and have been commercially available since the mid 1980's. PVDF has advantages, as opposed to ceramics, to be directly compatible with semiconductor technology, and a lower thermal conductivity.

An improvement of the technology of integrated pyroelectric sensors is achieved by coating the silicon substrate containing readout electronics, with vinylidene fluoride trifluoroethylene (VDF/TrFE) copolymer. Other than PVDF, the VDF/TrFE copolymer is pyroelectric without mechanical stretching [1]. A very thin copolymer (1-10 µm) can be deposited on silicon using a spin-coating technique [2]. Copolymer manufacturing and recrystallization are low-temperature processes ($T_{max} \approx 160\ ^0C$)[3]. In this paper, the deposition process of 65/35 VDF/TrFE copolymer films is described.

A pyroelectric sensing element consists of a pyroelectric VDF/TrFE copolymer with aluminium electrodes on both sides. The bottom electrode is connected to readout electronics. On-chip poling of the copolymer is achieved at room temperature and without damaging the readout electronics [4]. The manufacturing and poling processes are compatible with IC technology. This allows the realization of integrated pyroelectric sensors based on the VDF/TrFE copolymer.

FET's are used in the readout electronics because of low noise. The properties of the FET's will be presented. Finally, pyroelectric properties such as voltage sensitivity and noise are presented.

2. TECHNOLOGY

A pyroelectric detector generates an electric charge. This charge is directly supplied to the gate of a JFET. Therefore, the distance between the sensing element and the electrical signal conditioning circuitry is minimum and there is almost no deterioration of the signal due to external interferences.

The FET readout electronics has been realized in the DIMES01, double metal layer process at the DIMES Laboratory of the Delft University of Technology. Parameters of the FET are given in table 1. Figure 1 shows the

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vertical cross-section of the layout of a single pyroelectric sensor (not to scale). The biasing resistor R_{bias} is outside the chip area. It is not integrated on the chip, due to the difficulty to realize a high R_{bias}. The amplification resistor R_{load} is located near to the extended gate array at the topside of the chip.

Table 1
Properties of the FET readout electronics.

Property	Size	Units
Gate area	400	μm^2
Extented gate-oxide thickness	0.3	μm
Extended gate area	200x200	μm^2
I_{DSS}	0.8	mA
g_m (I_D= 0.4 mA)	0.76	mA/V
W/L	100	
β	0.36	mA/V^2
f_0	1	kHz
V_p	1.5	V

A larger piece of aluminium bottom electrode (the so-called extended gate), located on the chip surface and defining the pixel is connected to the gate of each FET. This extended gate has an extra external connection. The distance between two extended gates is 200 μm. The top electrode of the VDF/TrFE sensing element is connected to ground.

The copolymer sample was formed using 65 mol% vinylidene fluoride and 35 mol% trifluoroethylene, supplied by Solvay & Cie, Brussels, Belgium, in powder form. One gramme of VDF/TrFE is dissolved in methyl ethyl ketone at 80 °C, resulting in a 10% concentration VDF/TrFE copolymer. During the mixing process, the solution sample is heated up to 100 °C. After the copolymer is completely dissolved, the solution is filtered and cooled.

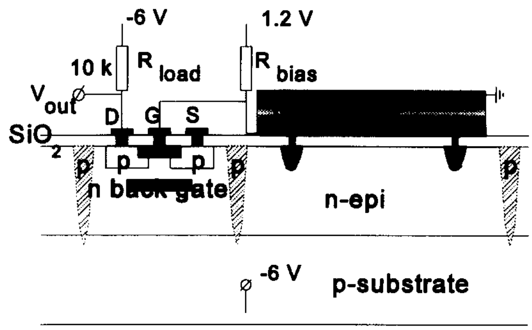

Figure 1 Vertical cross-section of the layout of a single pyroelectric sensor.

The solution is spun on the silicon substrate. The thickness of the VDF/TrFE film is mainly determined by the concentration of the copolymer solution, the spinning rate and the spinning time [3]. The thickness of 1 μm copolymer film has 5% uniformity. The sample is annealed as follows: first, the sample is kept for 24 hours at 25 °C. Then, the annealing temperature is increased to 100 °C. The sample is kept at this temperature for six hours, and an anneal for 10 minutes at 160 °C follows. Finally, the annealing temperature is slowly decreased to 25 °C in 4-5 hours. This annealing is done to recover the local stresses, to enhance the crystallization, to improve the adhesion between the copolymer and the aluminium, and to evaporate the remaining methyl ethyl ketone solvent.

Vapour deposition of HMDS (hexa methyl disilazane) has been conducted to improve the adhesion between the copolymer and the aluminium layers. This process is performed twice, first before spin-coating of the copolymers, secondly after the annealing step. Finally, a 250 nm aluminium top electrode is deposited.

The copolymer film is poled by a step-wise poling method. A dc field is applied between the bottom electrode (extended gate) and the top electrode. This poling treatment is carried out at room temperature. After the poling treatment, each chip is glued to a DIL 40 housing and aluminium wire bonded.

The step-wise poling is performed by a series of pulses of several minutes, and with increasing height. The pulse width is four minutes and the interval between two pulses is two minutes. The maximum applied field strength is 100 V/µm, with a constant increase of 20 V/µm. The step-wise poling method is described in more detail somewhere else [5].

The absorption of an aluminium electrode is very low. Therefore, the top electrode is covered by a thin black layer which provides a sufficient absorption.

3. EXPERIMENTAL RESULTS

Electrical properties of the VDF/TrFE copolymer, such as dielectric loss, dielectric constant and pyroelectric coefficient, which are related directly to the pyroelectric activity have been measured. Table 2 shows the electrical properties of the 65/35 VDF/TrFE copolymer. These values have been measured at 22 °C.

Table 2
Electrical properties of the 65/35 VDF/TrFE copolymer.

Property	Size	Units
Pyroelectric coefficient	2	nC/cm^2K
Dielectric constant	13.1	
Dielectric loss	0.034	

The sensitivity of the integrated pyroelectric sensors depends on the thermal behaviour of the sensor and the electrical transfer function of the readout electronics. The thermal behaviour is determined by the structure of the sensor [6]. Moreover, it depends on the chopper's modulation frequency. At low modulation frequencies, the influence of the silicon substrate is noticeable. The electrical transfer function of the readout electronics depends on the properties of the FET's and the additional circuitry (R_{bias}).

Figure 2 shows the measured and calculated voltage sensitivity of the pyroelectric sensors as a function of the modulation frequency. Here, the structure of each sensor element is the same. Hence, the difference in voltage sensitivity is only attributed to the readout electronics. Increasing of R_{bias} results in increasing of the voltage sensitivity at frequencies below 1 kHz. Moreover, the electric time constant depends also on R_{bias}.

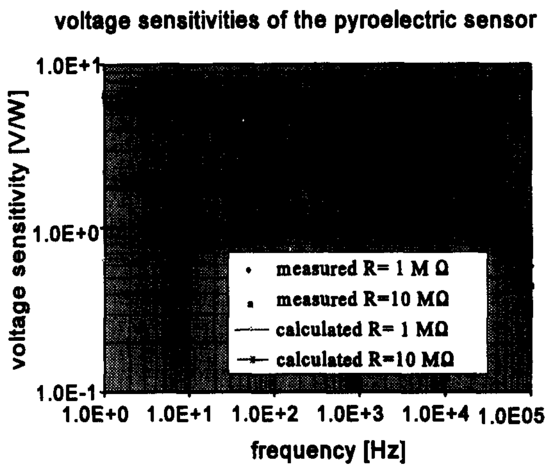

Figure 2 Measured and calculated voltage sensitivities of a pyroelectric sensor element for R_{bias}= 1 and 10 MΩ.

4. NOISE SOURCES

There are several noise sources in the pyroelectric sensor. They can be modelled by three sets of equivalent noise sources, for respectively the detector noise of the pyroelectric sensor element, the FET noise and the noise of the additional circuitry.

The main noise sources of the pyroelectric detector itself are (1) thermal fluctuation noise, (2) Johnson noise, and (3) dielectric loss noise. A FET contains the following dominant noise sources: (1) gate current shot noise, (2) the channel thermal noise, and (3) the flicker noise or 1/f noise. The biasing resistance R_{bias} connected to the gate of the FET and the load resistance R_{load} connected to the drain will give rise to thermal noise. The total noise at the output of the sensor can be calculated as the quadratic sum of the various contributions of the individual noise sources.

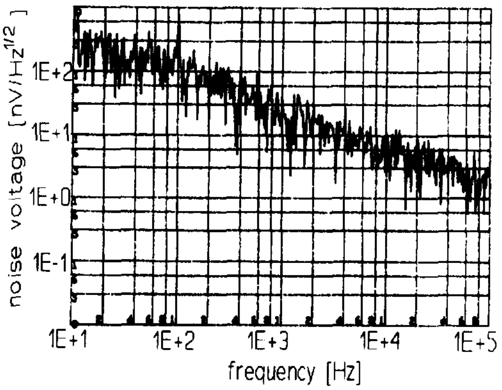

Figure 3 Measured voltage noise of the pyroelectric sensor element for R_{bias}= 1 MΩ as a function of the frequency.

Figure 3 shows the measured voltage noise of the pyroelectric sensing element for R_{bias} = 1 MΩ as a function of the frequency. It is found that the voltage noise decreases with increasing frequency, from 200 nV/√Hz at 10 Hz to 2 nV/√Hz at 100 kHz. From the slope of the voltage noise line, it can be concluded that the flicker noise or 1/f noise of the FET dominates the noise sources. This agrees with noise calculations.

CONCLUSIONS

A 3x1 integrated pyroelectric sensor based on VDF/TrFE copolymer has been realized. On-chip poling of the copolymer film at a relatively low voltage has been achieved. The voltage sensitivity depends on the R_{bias}. The voltage noise decreases with increasing frequency, and it is 2 nV/√Hz at 100 kHz. The flicker noise or 1/f noise of the FET dominates the noise sources.

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