PYROELECTRIC APPLICATIONS
OF THE VDF-TrFE COPOLYMER

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ABSTRACT

VDF/TrFE pyroelectric sensors have now definitely reached the level of a product. Based on a bidimensional staring array, it can be considered as a whole system with a monolithic technology processed on a silicon substrate provided with the integrated read out circuit.
The paper will describe the main procedures dealing with the elaboration of a 32x32 Focal Plane Array developed, in the context of the PROMETHEUS PROCHIP European Program (EUREKA), as a passive infrared obstacle detection (1) applied to automotive. Additional experimental data suggest that this microsystem could operate in space environment.

INTRODUCTION

A few years after the emergence of copolymers as pyroelectric elements, the high grade material currently commercially available (2) and its capability to be processed on a silicon substrate in a way similar to any microelectronic system, offer a real chance of industrial development to these sensors. Large sectors of industry dedicated to mass production like automotive, but also, medecine, agronomy, space... are concerned, and new developments of the Microelectromechanical system (MEMS) which can be adapted to the technology of these sensors deserve to pay attention to a material, which appears as a true challenger of 'high tech - low cost' infrared detectors already present or arriving on the market.
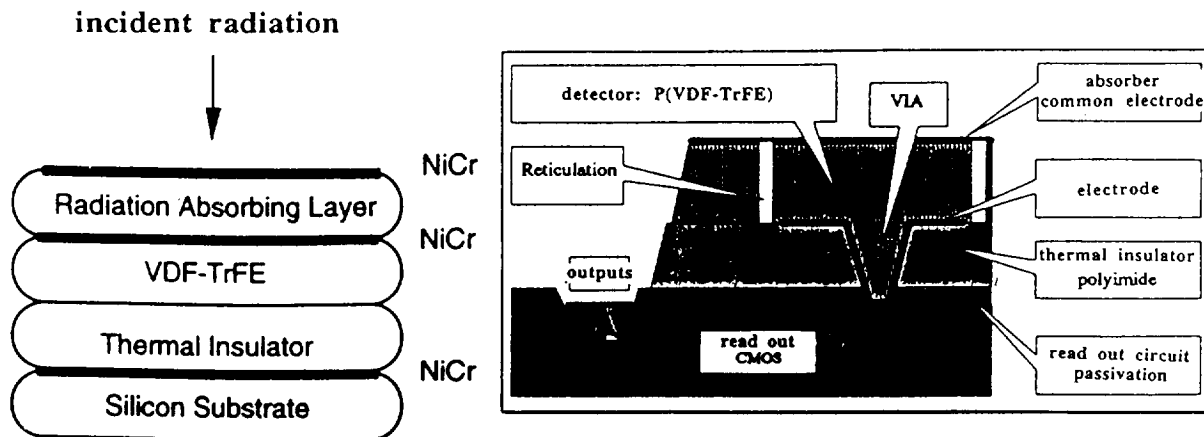

Fig.1 Basic Sensor Structure   Fig.2 Detector array - Pixel cross-section

This paper intends to describe the latest development achieved in the design and the technology of a 32x32 copolymer VDF-TrFE staring array, associated with a focal plane, and coupled with a signal processing circuit integrated in a silicon substrate.

The heterostructure (Fig.1) basically includes:

- a copolymer layer (VDF,0.7 - TrFE, 0.3) allowing the pyroelectric detection after absorption of the chopped incident infrared radiation; converted into a temperature variation, it will induce a pyroelectric signal between the electrodes deposited above and underneath the copolymer. This material is provided on top with a thin absorber film.

- a silicon substrate in which the read out circuit is processed in a 1.2μm C.MOS technology.

- a thermal insulator (polyimide), sandwiched in between copolymer and silicon, which improves the thermal sensitivity of the pixels.

ELABORATION OF THE STARING ARRAY

A schematic partial cross-section of the array is displayed in Fig.2, showing the different layers of the heterostructure. The 'via' allows to connect electrically copolymer and signal processing circuits.
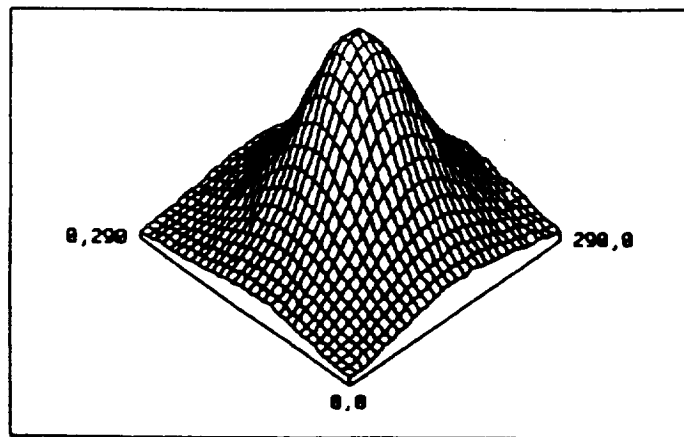
a)
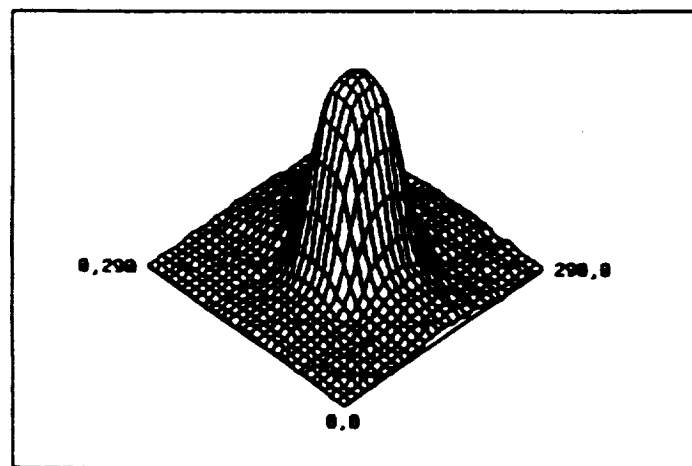
b)

Fig.3 Cross-talk 3D map of a pixel (pitch 100μm)
a) when the whole area is covered
by the copolymer layer
b) when the copolymer is reticulated

Three main steps were successfully completed to validate this approach:

- the copolymer, which cristallizes directly in a beta polar phase, is available under a liquid form and deposited by spin coating upon its support (polyimide+silicon). The real difficulty is to perform the poling procedure across the whole heterostructure already provided with the read out circuit. This has been achieved without any damage of the electronic circuit. The method used, first developed by F.BAUER (3), consists in the application of a very low frequency electric field (0.1Hz) at room temperature, allowing to generate many times the hysteresis loop while the magnitude of the field is increased continuously up to a limit slightly under the breakdown voltage of the material $(3 \times 10^8 \text{V/m})$. Reproducible values for the remanent polarization, equal or higher than $8 \mu\text{C/cm}^2$ are commonly reached.
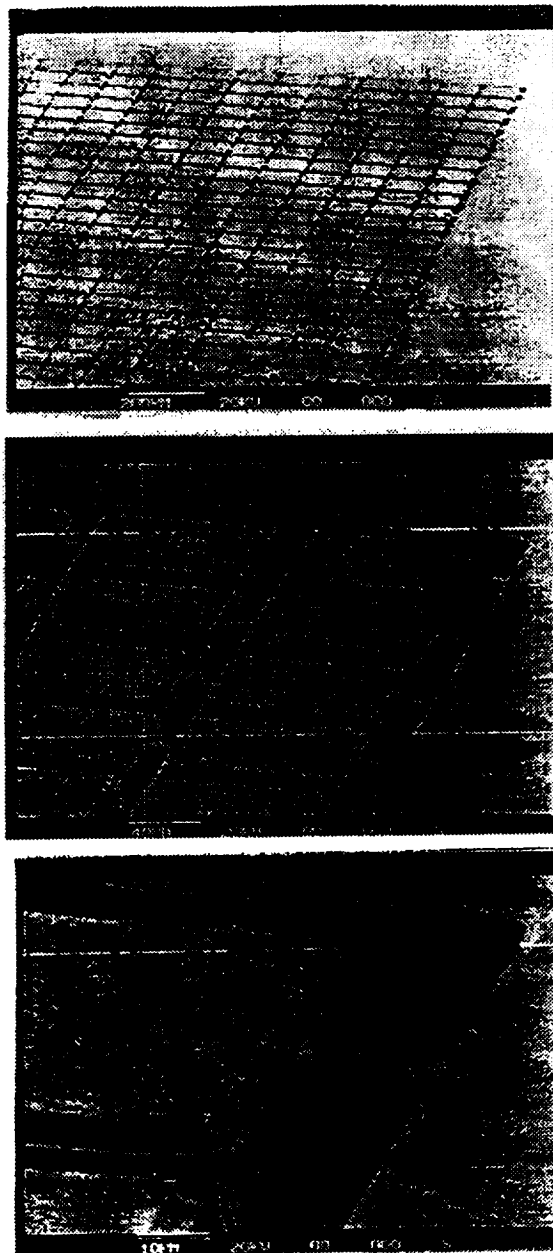

Fig.4   Dry etching for reticulation of the sensor array

- The low thermal conductivity of (VDF-TrFE) should allow to avoid any reticulation of the copolymer layer in the matrix array; However, according to Broadhurst et al (4) and confirmed by our experiments, a large part of pyroelectricity in this material is mostly due to a coupling between piezoelectricity and thermal dilatation of the material rather than to the variation of the spontaneous polarisation in the crystalline phase at constant volume. For this reason and for its beneficial impact on the thermal cross-talk as well, the reticulation by oxygen plasma etching of the different layers constituing the active part of the detector - metal, absorber, copolymer - has been successfully tested; this procedure allows a maximum of deformation under the effect of a temperature variation, improves the pyroelectric coefficient, and a minimum thermal cross-talk has been also checked after this procedure (fig.3). A SEM picture of the reticulation is shown in figure 4.

- The signal processing silicon circuit has a direct impact on the sensitivity of the sensor. A first system (IRPY1) elaborated has demonstrated the necessity to reduce the fixed pattern noise by a self calibration integrated at the level of each unit pixel. Therefore, a second generation (IRPY2) has been designed, including a reduction of the read out capacitance and of the access resistances, allowing a significant decrease of the whole area by a factor 2 (see the picture of both sensors on their headers).

In order to optimize the performance of the sensor, the theoretical analysis of the response of the array has been investigated through the thermal diffusion model adapted to a general heterostructure by Shu-Yau Wu (5), and through a second model based on a network of distributed thermal resistances and capacitances associated to each layer, to include the effect of the 'via' on the thermal behaviour of the sensor.

As a result, a thickness of $17\mu m$ for the copolymer, and of $10\mu m$ for the polyimide have been selected in the project.(4). The thermal cut off frequency has been optimized below 50Hz for the frame rate application of 10Hz.

The read out circuit is a 32 lines x 32 columns, $100\mu m$ pitch staring array. The pixel signals are addressed by lines and the internal data bus buffers are multiplexed to the video amplifier. Fig.5 gives a schematic view of the array architecture whose characteristics are detailed in Ref.(6).
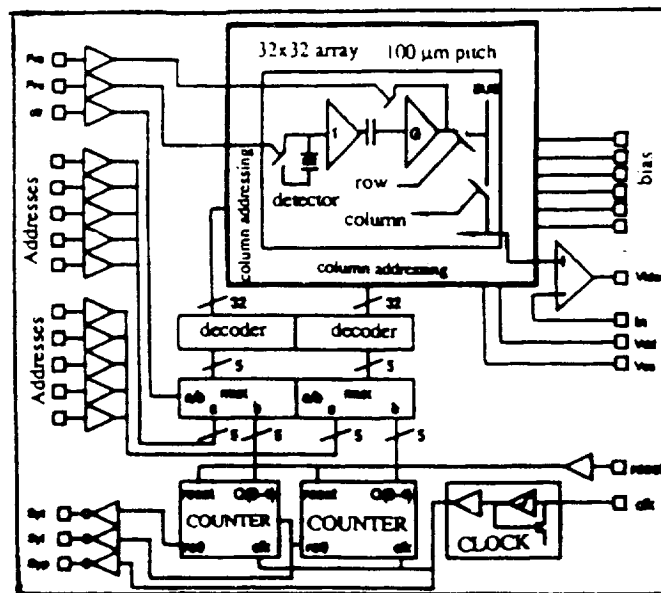

Fig.5   Copolymer Focal Plane Array: Architecture
of the read out circuit

SENSOR PERFORMANCE

Interest of (VDF-TrFE) in the present application does not rely on its pyroelectric coefficient, fairly low when compared to other traditional pyroelectric materials (see Table 1). Other parameters like dielectric constant (fig.6) and loss tangent (fig.7) have hopefully a direct impact on the sensor performance and allow the copolymer to exhibit a good voltage merit factor. In addition, the material does not require costly preparation, is insensitive to humidity, is chemically inert, stable, and, as already said, available under a liquid form, properties which make it attractive in IR imagery.

Improvement on two particular performances has been emphasized: sensitivity and noise properties.

Material	Form	Curie point °C	Pyroelectric coefficient nCb/cm²/K	Permittivity F/m	Thermal diffusion cm/°C	Voltage readout merit factor	Charge readout merit factor
TGS	Crystal	49	35	50	72	7	4.9
LiTaO₃	Crystal	620	17	43	-	4	2.6
PbTiO₃	Ceramic	490	30	200	140	1.5	2.1
PZT	Ceramic	> 300	35	300	110	1.2	2
P(VF₂-TrFE)	Copolymer	125	4	7	20	5.7	1.5

Pyro-electric materials : properties, performances and ability to readout.
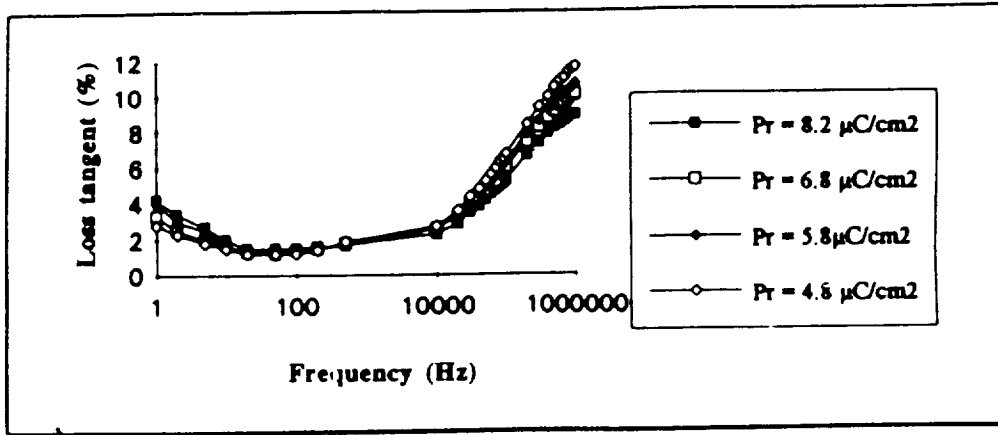
Table 1
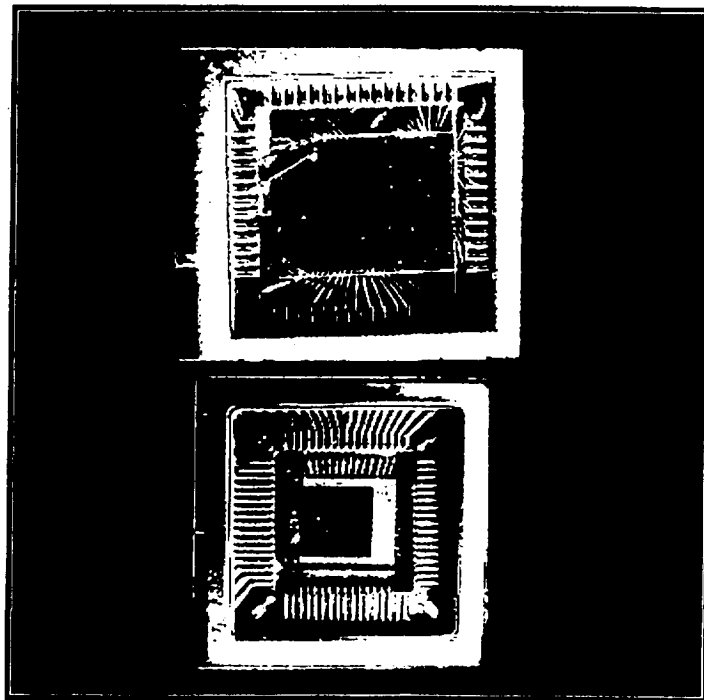
32x32 pyroelectric copolymer arrays

Fig.6 tgδ versus f for several remanent polarisation P_r
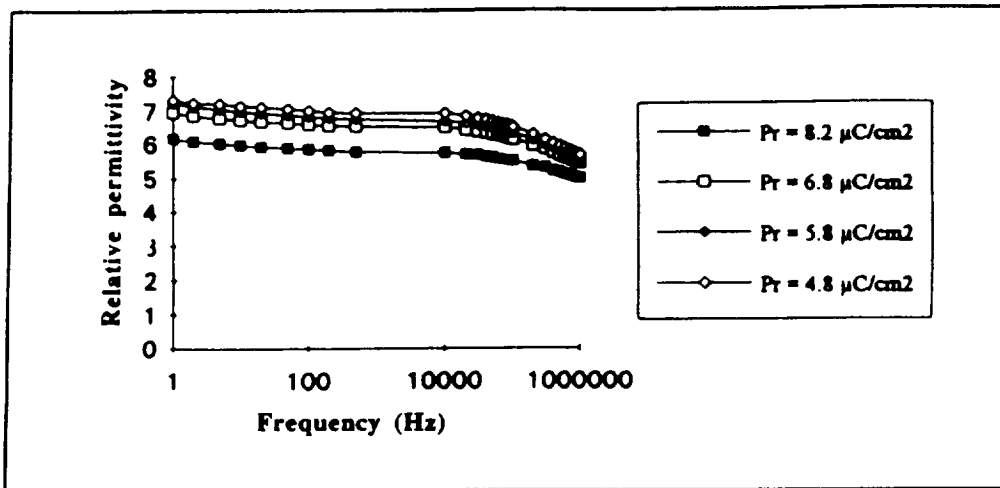(tgδ is minimum between 10 and 200Hz)

Fig.7 $ε_r$ versus f for several remanent polarisation P_r

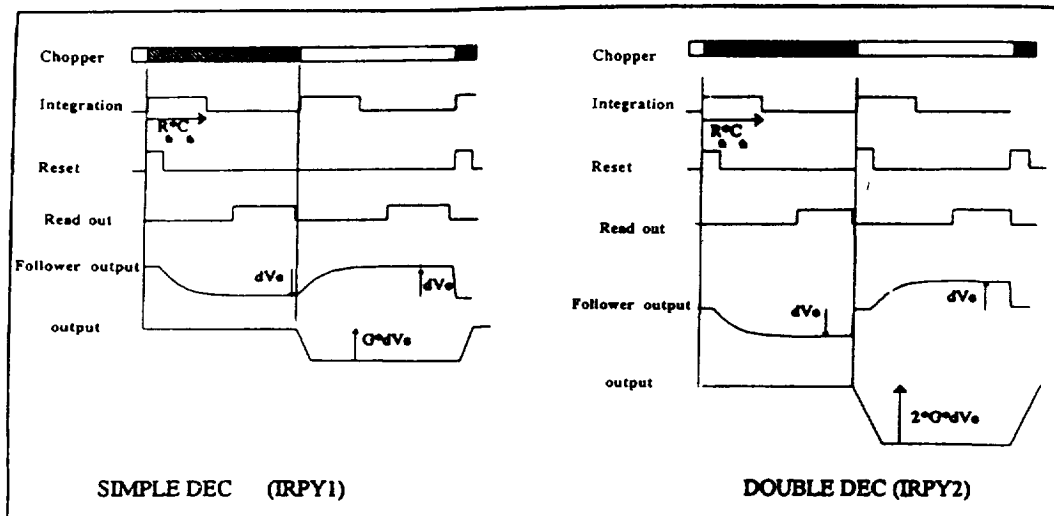SIMPLE DEC   (IRPY1)   DOUBLE DEC (IRPY2)

Fig.8

- concerning the sensitivity, a double correlated sampling (double DEC), using the subtraction of the signals generated in both initial positions of the chopper inducing in a pixel +ΔT (aperture), then -ΔT (shutting), allows to double the response (fig.8).
- concerning noise properties, the fixed pattern noise is ruled out by the double DEC procedure, while other noise sources have also been shrunk by optimization of the connexion lengths, leading to the circuit lay out of the second generation. Figure 9 and figure 10 illustrate the improvements of the responsivity and of the Noise Equivalent Temperature Difference (NETD) with both technologies IRPY1 and IRPY2, including different upper electrodes.
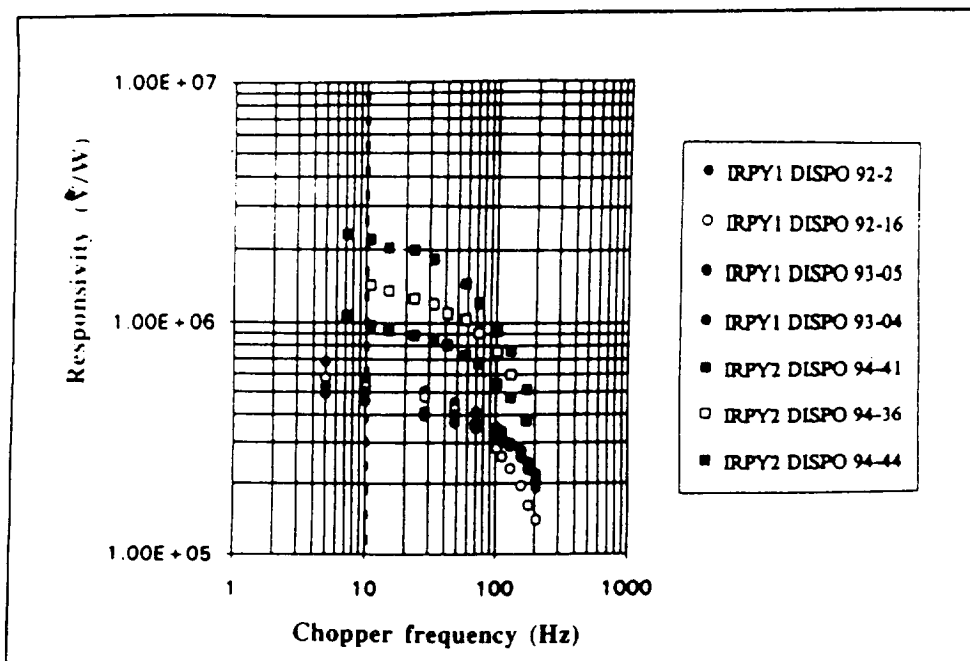

Fig.9   Evolution of the responsivity with the improvement
of the technology.
nature of the upper electrode: 92-2 thin Cr layer;
92-16 graphite spray; 93-05 thin Cr layer;
93-04 thin Cr layer; 94-41 absorber; 94-36 thin Cr layer;
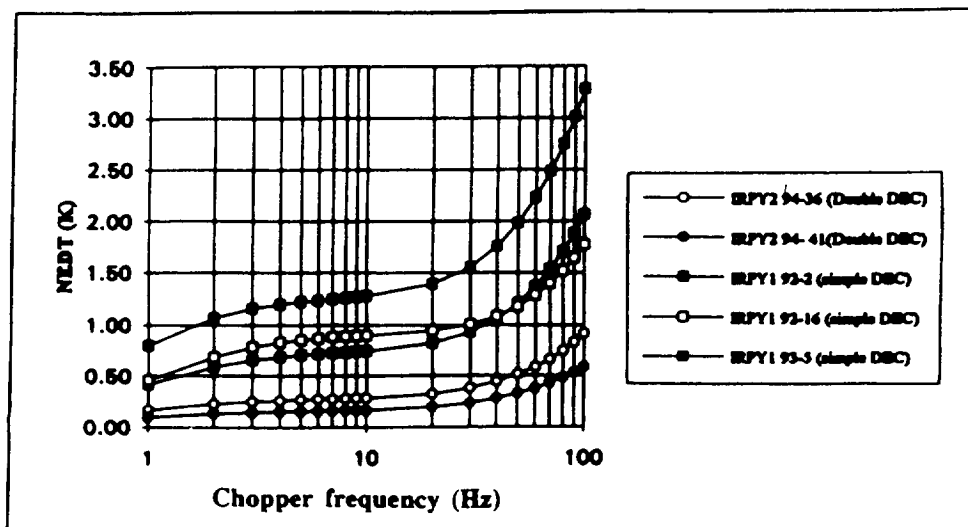94-44 reticulated absorber.

Fig.10   Noise properties for different technologies
(se fig.9 for the nature of the upper layer)

The NETD histograms presented in figure 11, with an ideal optic transmission and a F/1 numerical aperture, give a mean measured value of 0.40K performed on all pixels of the IRPY2 array, which could be even decreased to 0.16K as noticed through simulation on the same figure.
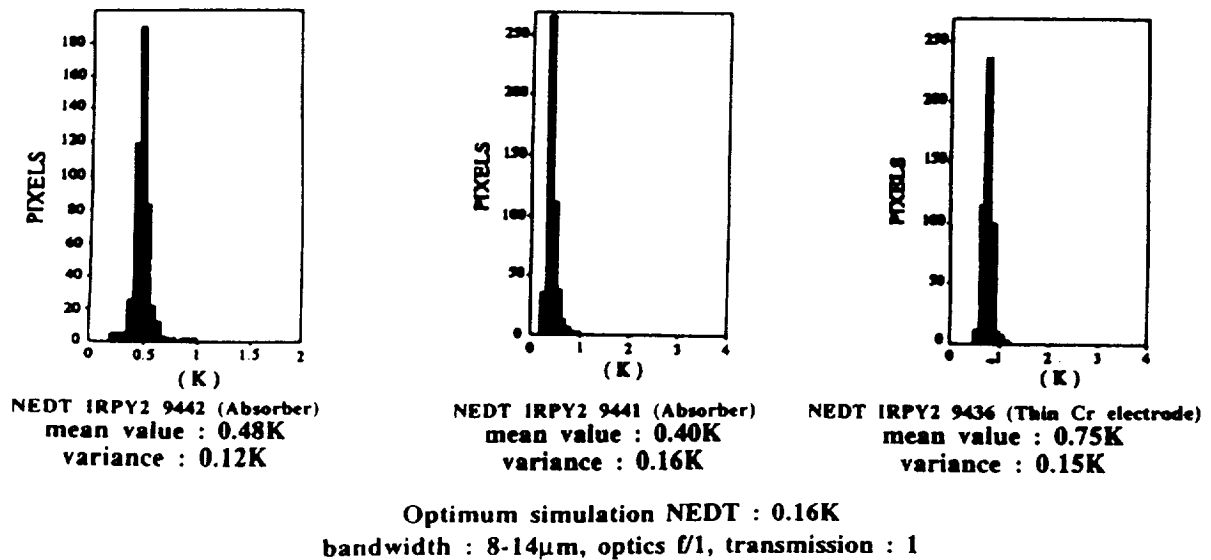

NEDT IRPY2 9442 (Absorber)
mean value : 0.48K
variance : 0.12K

NEDT IRPY2 9441 (Absorber)
mean value : 0.40K
variance : 0.16K

NEDT IRPY2 9436 (Thin Cr electrode)
mean value : 0.75K
variance : 0.15K

Optimum simulation NEDT : 0.16K
bandwidth : 8-14μm, optics f/1, transmission : 1

Fig.11   NETD Histograms of the IRPY2 devices

COMMENTS

This project has demonstrated the capability of VDF-TrFE to be processed as a pyroelectric Focal Plane Array dedicated to infrared imagery, with latest performances able to reach those presented in recent alternative solutions, namely the microbridge resistive bolometer array developed by Honeywell (7), and the hybrid dielectric bolometer processed by Texas Instruments (8). This copolymer thin film heterostructure and a micromachined linear array also implemented elsewhere (9) make clear that the Microelectromechanical systems (MEMS) will be the most predictable approach selected for 'high tech-low cost' IR imagers.

If automotive has been the driving force of this application, this Conference is a good opportunity to examine how space can be also considered as a potential field for this material. Tests experimented at different temperatures have demonstrated a working stability between -50°C and +50°C before unfolding, and in the range'-150°C/+150°C, when operating outside. Stability with time in another useful factor in favour of copolymer, property which emphasizes the role which could be played by this system in the payload of a satellite: a 10 years storage does not disturb the response of the active material. Furthermore, we must keep in mind the tremendous characteristics of (VDF-TrFE) in piezoelectricity, demonstrated in shock compression (10) and accelerometer applications (11). Some early successful tests have been made to examine the behaviour in a heavy ion ambient and more investigation is likely needed to check its properties versus other kinds of charged particles; nevertheless, in a period where the space technology is going to know a huge transformation, capabilities of the pyroelectric and piezoelectric copolymer cannot be ignored, even if additional data must be provided to state whether they appear as a useful approach to the space field.

ACKNOWLEDGEMENTS

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