Low-cost Platform Technology for LWIR Sensor Arrays for Use in Automotive Night Vision and Other Applications

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Abstract

In the EU FP7 project 'ADOSE' a new approach has been used to develop a new cost efficient technology by adapting a volume proven integrated MEMS process for the production of a suspended thermodiode array. As low-cost was to be the key feature of the project the focus was set on fully semiconductor compatible production without the need for dedicated equipment and on the use of cost efficient MEMS technologies like wafer-level vacuum encapsulation. A first proof-of-concept integrated FIR array with 42 x 28 pixels was already published [1], now the final ADOSE design with 100 x 50 pixel resolution is produced and under evaluation. While the ADOSE chip targets the requirements of a low-end "Hot-Spot-Detector", many applications require higher resolutions. As the technology used in ADOSE inherits some limitations from its pressure sensor ancestor, we advance the technology to get rid of these and achieve a low-cost and high-res imager. Here we present the results from ADOSE and give an outlook on the new BMBF-funded Spitzencluster MicroTEC Südwest project RTFIR.

1 Introduction

The EU FP7 project ADOSE targets a variety of low-cost and high performance sensor technologies that enable reliable detection and classification of vulnerable road users and obstacles and through this enhance active safety functions. The project is focused mainly on the sensor technologies, the sensing elements and some pre-processing hardware and only to a minor degree on system concepts and software. Besides the thermal infrared camera presented in this paper the following sensory concepts are part of ADOSE: multifunctional CMOS imagers, 3D packaging technologies, ranging techniques, bio-inspired silicon retina sensors, harmonic microwave radar and tags.

The Spitzencluster MicroTEC Südwest project RTFIR is focused on thermal imagers but targets also applications abroad automotive like industrial process control, ambient assisted living and security technology. As in ADOSE the projects deals with the technological aspects and the sensing principle primarily and not with the system or software aspects other than needed for testing and demonstration of the technology.

1.1 Automotive Night Vision

Currently available high-end systems in luxury and upper class cars either focus on excellent image display and use the combination of a NIR CMOS imager and additional NIR headlights or make use of stand alone FIR night vision with expensive high resolution bolometers. Next generation automotive night vision systems for driver assistance will improve the safety of vulnerable road users with active warning signals and in future systems also automatic system action. Reliable detection with low false alarm rates is essential for such systems. With current technology only the combination of NIR and FIR is able to fulfil all requirements but this makes the systems even more expensive. A fused NIR/FIR system combining high resolution NIR and lower resolution FIR would allow excellent image display quality using the active NIR image from affordable good resolution CMOS image sensors and at the same time provide the additional information required to reliably identify vulnerable road users through the support by hot spot detection from a low-cost mid-res FIR-array sensitive in the 7-14 µm wavelength range (see Fig. 1).

Hot-spot detection has some advantages towards low-cost realization compared to stand alone FIR imaging as the resolution requirements both in thermal and spatial view are significantly lower when the thermal imager is combined with a VIS/NIR CMOS camera with higher spatial resolution. The latter can then be used for purposes like road sign detection, lane departure warning or others using image recognition anyway while the thermal imager provides the information about thermal properties of objects.

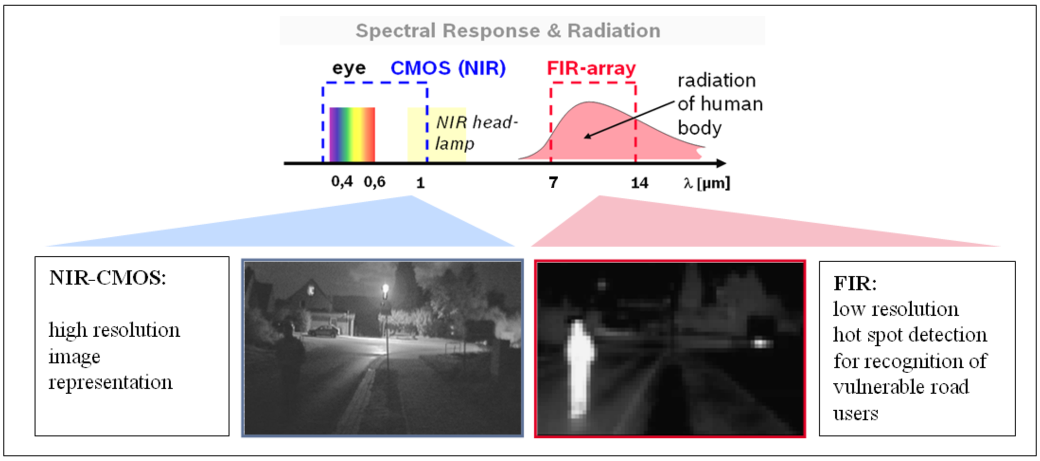

Fig. 1 Multi-spectral approach for warning night vision with NIR / FIR data fusion (top); identical night vision scene with different sensors (bottom): CMOS-NIR imager without active light (left) and low resolution FIR-array (right).

2 Requirements

2.1 ADOSE

In the specification part of ADOSE different use-case were analyzed and the use-case of extra-urban single lane roads with a maximum velocity of 100 km/h was chosen as the base for the specification of the sensor modules. For a safe break in this scenario a detection distance of 120m was calculated. The minimum hot-spot for detecting a human being has been set to 1 by 5 pixels (hor. x ver.). Together with the viewing angle necessary for usual curved roads of +-12° the spatial resolution of 100 by 50 pixels was derived. The thermal resolution was specified to 0.5K.

FIR camera requirements		**Remark**
Hor. Field of View (FOV):	± 12°	For data fusion with NIR
Angular Resolution:	4,18 pixel / °	Defined by smallest object to be resolved @ 120m
Object Temperature resolution:	< 500 mK	for hot-spot detection; no greyscale image display NETD < 300mK for chip @ F#1 optics
Frame Response:	> 12,5 Hz	for 3 verifications of object in the NIR image
Array Size:	100 x 50 pixels	Defined by FOV and angular resolution
Wavelength Range:	7-14 µm	Spectral emission maximum of vulnerable road users

Table 1: ADOSE FIR add-on module specifications

Looking at the cost for the imager chip used in an FIR add-on module only a few tens of euros seem to be acceptable, because there is another major cost part – the optics. We looked into low-cost FIR optics in ADOSE as well but the results from this will be published later.

2.2 RTFIR

In RTFIR the required specification comes form several different application with different requirements. For the automotive application the target is to address not only the limited use-case of ADOSE but also use-cases were higher spatial resolution is necessary. To achieve this, the sensor technology and the read-out concept will have to focus on scalability so a wide range of resolutions may be produced just by altering layout to utilize economy of scales. This effect would vanish when different resolution would require different processing and therefore the “low-cost” would be feasible for high volume applications only. Because of limited resources the somewhat standard resolution for un-cooled thermal imagers of 320 x 240 has been chosen as the single resolution to proof and demonstrate the concept and technology. For the thermal resolution the target is 100mK for the automotive set-up.

3 Sensor Technology

3.1 ADOSE

As the technological concept of ADOSE was already described in detail in [1], here we just present a short overview of the process and concentrate on the design improvements made since then.

In order to make use of the existing mass-production and cost effective RB pressure sensor technology we decided to differ from the standard resistive sensing principle of microbolometers and use the forward voltage of a diode made in monocrystalline silicon. This type of sensing element is available in the IC-process of the integrated pressure sensor without the need of additional masks or material layers and comprises very low noise. Also we used the dielectric layers of the process as the absorption structure to save costs for a reflector and $\lambda/4$-structure as are used in microbolometers. The thermal insulation of the sensing element is achieved by structuring the pressure sensor membrane. The vacuum encapsulation is done by a silicon cap bonded on wafer level using glass-frit bonding as it is known from inertia sensors (see fig. 2).

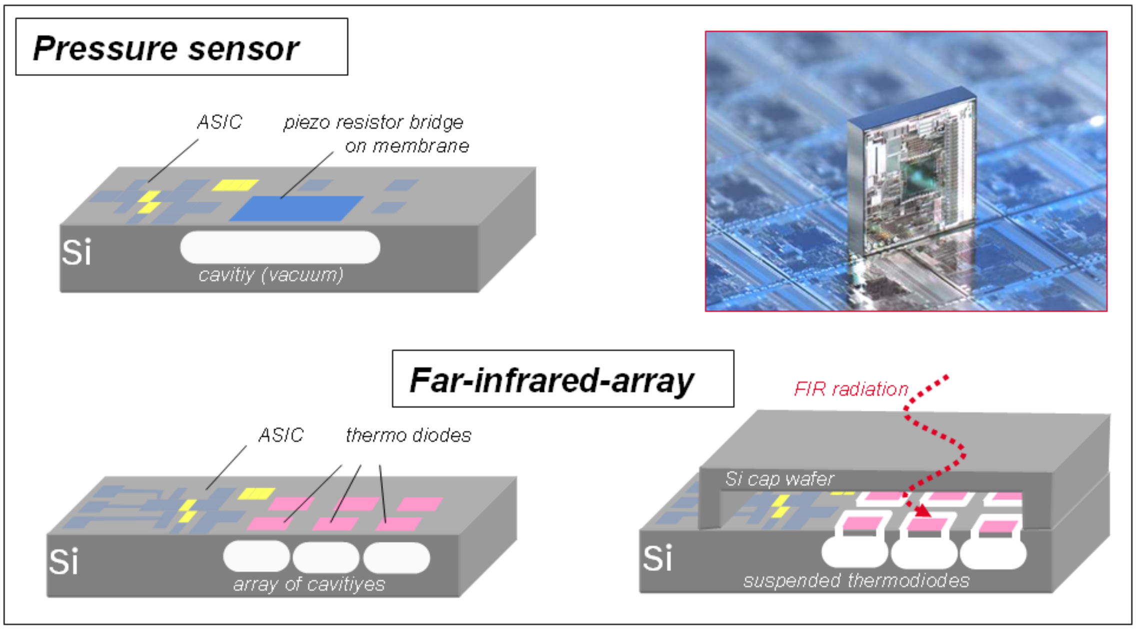

Fig. 2: From integrated pressure sensor to thermal imager. Top left: integrated pressure sensor principle; top right: picture of an integrated pressure sensor, the membrane is the square in the centre of the chip; bottom left: Instead of a single cavity for the pressure sensor an array of cavities is made (one beneath each pixel); bottom right: fully vacuum packaged thermal imager.

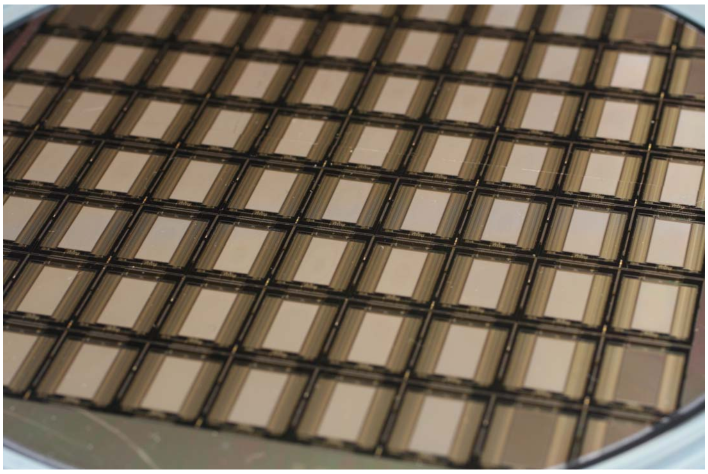

Fig. 3: Photograph of first ADOSE wafer

3.2 RTFIR

The process for RTFIR is not finally chosen, but the concept is clear. The main inhibitors for higher resolutions within the ADOSE process are the restriction of process parameters coming from the combination of a MEMS and an IC process. So the first step is to separate the MEMS and the ROIC and the second step is to find a way to contact both as a classic two-chip approach is not feasible with a large pixel array because of too many connections and the vertical integration approach of microbolometers where a CMOS ROIC is used as the substrate for the MEMS layers is too expensive. With the separation of the two parts both of them may be optimized independently, e.g. the membrane thickness for the MEMS may be reduced and the thermal regime of the process steps has not to be limited to CMOS compatibility levels. For the ROIC modern CMOS processes with 0.35µm structures or lower may be used to increase functionality and decrease chip size and cost as well.

4. Pixel Design

The main issue for the design of the sensor pixel is to maximise thermal insulation and fill factor to get the highest signal out of the radiation incoming from the object observed. The second issue is to keep the thermal capacity of he pixel sensing element low in order to avoid high thermal time constants that would lead to smearing in the image.

In our last AMAA publication [1] we showed the thermal design and simulation of such a pixel in the ADOSE process. Unfortunately this design did result in too little signal and even if the insulation could be increased sufficiently, this would lead to too high thermal time constants, so we had to improve both parameters. One of the advantages of our forward current biased diode concept is the possibility to use more of them in a row to scale the signal. As the intrinsic noise of the monocrystalline diodes is very low, the SNR just scales with the number of diodes in series. Therefore we decided to place four diodes on the pixel structure instead of just one. A side effect of this was to be able to reduce the thermal mass by etching between the diode subpixels. Another measure taken to increase the signal was to improve the thermal insulation by using a different material for the electric contacts of the diodes. Fig. 4 shows the simulation results for such a four-fold diode pixel.

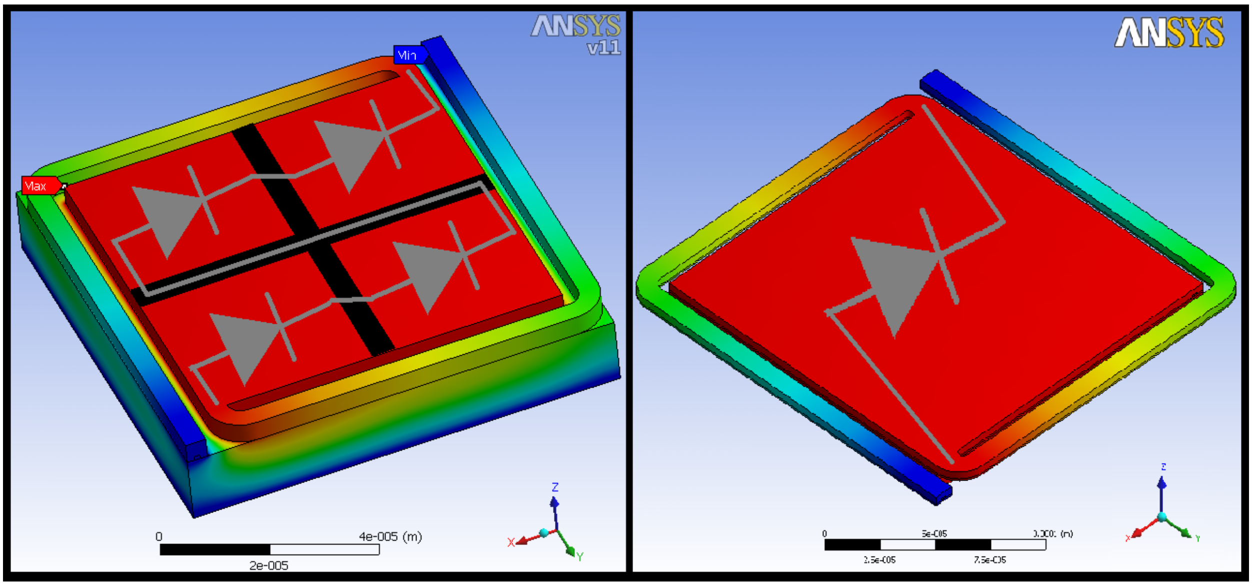

Fig. 4: Thermal simulation of a four-fold diode ADOSE pixel compared to the old single-diode design

For the RTFIR pixel design the main issues are a massive shrink of the pixels to keep the chip for the larger arrays at reasonable size and a drastic increase in insulation to countermeasure the loss of absorbed power resulting from the decreased pixel size.

Table 2 shows the design properties of our ADOSE pixel and gives an outlook on the planned properties of the RTFIR pixels.

	ADOSE	RTFIR
Pixel Pitch [µm]	100	25
Absorber area [µm²]	5000	256
Fill factor [%]	47	44

Table 2: Design properties of ADOSE and RTFIR pixel

5. Read-Out Concept

To achieve the frame-rates specified in ADOSE the ROIC was designed with a massive parallel pre-amplification stage. This stage was built as a switched-capacitor amplifier unit which allows adjusting the pre-amplification level and therefore the temperature range of the sensor by external timing. The parallelization was made column-wise, so one row is addressed and in each column the active pixel in that row is differenced to the reference pixel of that column and the difference is amplified by the SC-integrator. The analog output amplifier stage comprises an offset correction feedback, so fixed-pattern noise can be eliminated before the final amplification. Fig. 4 shows a schematic view of one pre-amplifier stage.

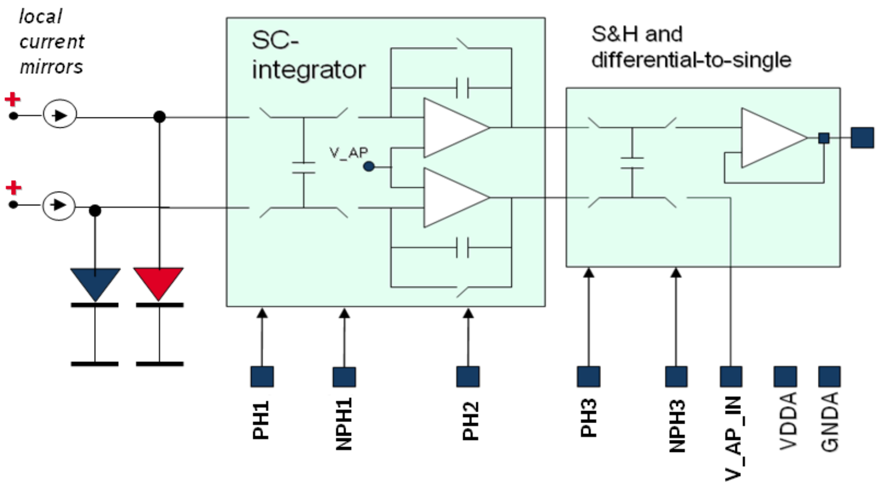

Fig. 4: Block diagram of SC integrator stage.

6. Results

First wafers with the ADOSE pixel and ROIC design have been produced and are currently under test. The thermal responsivity of the pixels meets the simulated values of about 8000 V/W, while the thermal time constant exceeds the simulated value. The reason is still under investigation.

7. Discussion and Outlook

The improvements to the pixels we applied seem to work as expected so after completing the implementation of the chip into the demonstrator board we expect to achieve most of the target specifications of ADOSE. The issues left are the thermal time constants and some cross-talk-problems in the ROIC. We expect to be able to complete a functional demonstrator before the end of the ADOSE project which is planned for august 2011.

In the next generation low-cost thermal imager project RTFIR we expect to improve the performance and specifications of our imagers significantly without adding significant costs.

8. Summary

A new approach to low-cost thermal imagers has been proposed and proven with a functional 42 by 28 pixel array. The improvements necessary to meet the ADOSE requirements were worked out and first silicon containing the according thermosensor-array has been produced. Also the concept for a future platform technology for low-cost thermal imagers with a wider resolution range has been described that may enable the application of thermal imaging at much lower cost and therefore bring the benefit of life-saving night vision system to middle and even compact class cars.

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References

[1] Reinhart, K.F., et al.,’Low-cost approach for Far-Infrared Sensor Arrays for Hot-Spot Detection in Automotive Night Vision Systems’, Advanced Microsystems for Automotive Applications 2009, pp397-408 Editors: G. Meyer, J. Valldorf and W, Gessner, Springer Berlin Heidelberg; ISBN 978-3-642-00744-6

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