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Low power consumption infrared thermal sensor array for smart detection and thermal imaging applications

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Abstract:
The high level of accumulated expertise by ULIS and CEA/LETI on the development and the manufacturing of InfRared (IR) thermal sensors arrays based on amorphous silicon microbolometer technology enables ULIS to develop a new generation of IR sensor thermal array, Micro80P™, with optimized power consumption that meets the needs of smart detection and low resolution thermal imaging applications. The ReadOut Integrated Circuit (ROIC) architecture of an 80x80 format sensor will be described where innovations are widely on-chip implemented allowing an easier operation by the user, in particular with the standardization of the sensor interfaces. Then, the paper will focus on the low power consumption management system embedded in the ROIC. Finally, packaging technology improvements will be disclosed, such as Pixel Level Packaging (PLP), offering highly cost-effective solutions.

Key words: thermal sensor array, smart detection

Introduction

ULIS is developing a new generation of IR thermal sensor array, Micro80P, which embeds low power consumption management that meets the needs of smart detection and low resolution thermal imaging applications. Based on amorphous silicon, a microbolometer technology industry proven for its performances and reliability, Micro80P has been designed to fill a capability gap in existing low resolution thermal detection sensors. This new IR sensor array offers the best tradeoff between performance and affordability thanks to innovative concepts implemented: a Focal Plane Array (FPA) of 80x80 pixels, on-chip low power management system, a small pixel pitch compatible with advanced pixel level packaging technique.

Readout Integrated Circuit Sensor design

The readout is operated in rolling shutter mode and achieves the resistance measurement of the IR microbolometer array. With the couple Cint and Tint set in the ROIC, respectively integration capacitor and integration time, the responsivity or thermal sensitivity characteristic of the microbolometer is expressed as:

$$\Re = \frac{V_{pol}}{R_0} * \frac{E_a . A . R_{th} . \Delta\phi}{k . T^2} * f(T_{\text{int}}, C_{\text{int}}) \quad \text{[V/K] [1]}$$

Where Ea (activation energy), A (membrane area), Rth (thermal insulation of the membrane) and Ro (electrical resistance of the thermometer), are parameters that depend of the microbolometer design, and particularly of the membrane area. This equation shows that the only electrical parameter the responsivity depends on, is the microbolometer Vpol bias voltage. As properties of amorphous silicon material offer an activation energy Ea identical for every pixel in the array, it means that the FPA behavior is highly uniform and predictable leading to easier device modeling and therefore easier TEC-less and shutter-less operation.

The Micro80P ROIC has been designed with 3.3V analog power supply and 1.5V digital power supply. A specific CMOS design enables to manage the power consumption in particular with the implementation of an advanced watch mode. Dedicated features were integrated in the ROIC towards the standardization of the Micro80P interfaces with digital processing systems. Therefore a 14bits Analog to Digital Convertor (ADC) is integrated in the readout circuit and the digital data is supplied on an 8bits multiplexed bus. The Micro80P configuration (integration time, gain, power consumption management…), is driven by a standard I2C link, and adopts the classical HSYNC/VSYNC free-run mode of operation driven by only one Master Clock (MC) supplied to the ROIC which feeds back pixel, line and frame synchronizations. With less than 1MHz MC frequency the Micro80P can work from 1Hz to 50Hz frame rate. Key FPA parameters are stored in a One Time Programmable (OTP) memory during ULIS manufacturing process, leading to an easiest integration into systems.

Power-consumption management

The design of the ROIC was focused on the power consumption reduction around the three main axes:

- The frame rate operation range from 1Hz up to 50Hz involves a maximum master clock (MC) frequency down to 780kHz. It enables the optimization of the amplifiers biasing in the analog part accordingly.
- The power consumption of the internal ADC is reduced down to 30mW thanks to the 780kHz maximum sample frequency. Consequently, the overall power consumption of the ROIC is less than 45mW, including 15mW of the analog part.
- The ROIC embeds on-chip implementation of an innovative dedicated power management system, detailed hereafter.

This dedicated power management system provides three power-consumption modes: standby-mode, nominal-mode, watch-mode. All these modes are programmable using the I2C interface of the chip.

In standby-mode, the sensor can be driven externally by the processor of the system to switch between standby-mode and nominal-mode. This standby-mode can be useful for advanced detection in energy saving application for example. In the case of a room monitoring for Heating, Ventilation and Air Conditioning (HVAC) system management, a sensor monitoring of 5 minutes cycle could be applied: the sensor is awakened every 5 minutes and records the temperature of the room's details during 3 frames of 1Hz; the power-up time is equal to 40ms and the power-down time is less than 100µs; depending on the ratio of the frame over the stand-by duration, the power consumption can be divided by a factor of more than 100. In this case, the typical power consumption of the standby-mode is less than 5µW.

In watch-mode, the ROIC is able to switch automatically from standby-mode to a reduced nominal-mode corresponding to the selection of a few pixels of the focal plane array called "watch pixels". This mode is controlled internally by digital processing, as shown in figure 1.

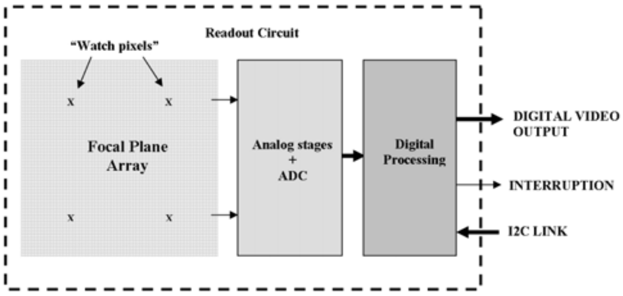

Fig. 1. Synoptic of the watch-mode device

The "watch pixels" are used to sense the activity of the scene, allowing advanced human presence detection for example. This detection generates an interruption towards the electronic system associated to the IR sensor and involves the external processing's wake-up. This operation enables the sensor to switch from watch to nominal-mode that uses the whole focal plane array and then confirms the activity. The main characteristic of the watch-mode is an autonomous functioning: it can work without any external clock. Indeed, an internal oscillator maintains a low power sequencer to manage activity detection. As described in figure 2, the watch-mode is periodically setting up during standby-mode following a programmable few hertz internal frequency.

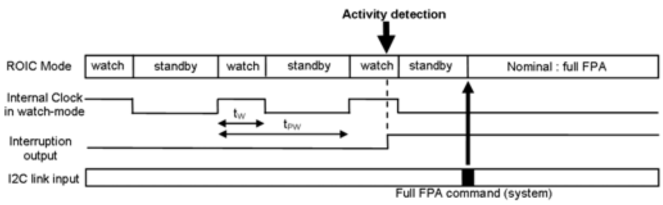

Fig. 2. Watch-mode timetable

Power-consumption measurement results

The ROIC power consumption in the 3 different modes is:

Nominal with analog Output	Nominal with ADC	Watch-mode with ADC	Standby-mode
15mW	45mW	Rx42mW	5µW

Where $R=t_W/t_{PW}$. For example, if t_W=500µs and t_{PW}=1s, the power consumption of the watch-mode is 21µW, corresponding to more than 2 years of autonomy with a 700mA/h battery.

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Packaging techniques

In order to be sensitive to the far infrared radiation input flux coming from the scene of interest, all the microbolometer FPA requires thermal insulation to the convection coming from the surrounding. This insulation is done by using second order vacuum package techniques, where residual pressure is lower than 10^{-3} mbar. Moreover, microbolometer FPAs work at ambient temperature and do not require any expensive, power and size consuming cooling or temperature stabilization system for operation. Since several years, ULIS has been engaged in the packaging cost reduction; as a result, ULIS introduced the first LCC vacuum packaging working without the need of thermo-electric temperature stabilization (TEC-less) in 2006 (figure 3). This packaging technology is today the standard used for the major part of the current IR imaging sensor production.

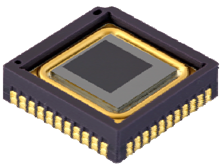

Fig. 3. Micro80P in ceramic package

ULIS, with the support of the CEA/LETI, is now investigating a new packaging approach, called Pixel Level Packaging (PLP)[i].
Basically, PLP process consists in the building of IR transparent micro-caps that encapsulate independently each microbolometer pixel of the array. To be efficient, the microcap has to be hermetically sealed under vacuum and maintain the vacuum level in the 10^{-3} mbar range requested for nominal FPA operation. The main point regarding cost reduction objective is that the PLP process is thoroughly carried out directly on the ROIC and microbolometers wafer, in a full collective way. This technology will suppress the usual costly vacuum package and integration process of the sensor chip.
A description of the monolithic cap structure can be found in references [2] and [3] and is recalled in figure 4. First, a sacrificial layer is deposited above microbolometers and a trench is realized at the periphery of each pixel. An IR window is then deposited in order to form the microcap structure. Two exhaust holes linked by an etch channel are etched through the top of the microcap. The capped sacrificial layers are removed through these exhaust holes and the etch channel. Finally, the sealing and anti-reflecting layer is deposited under high vacuum to finalize the hermeticity of the microcap. SEM views of PLP are presented in figure 5.

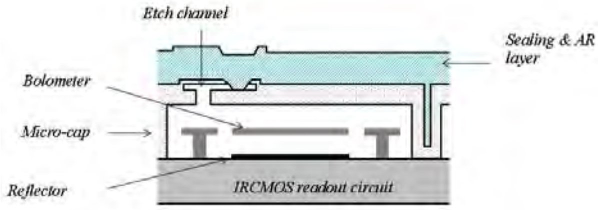

Fig. 4. Schematic cross section of the microcap

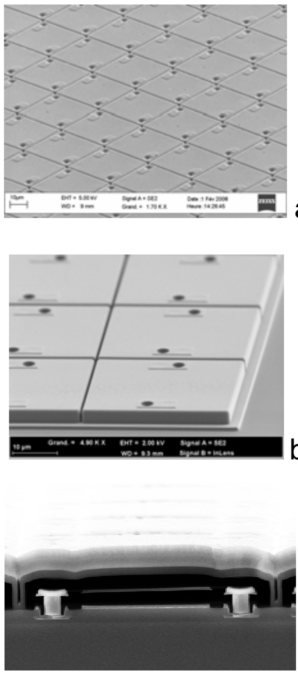

Fig. 5. SEM view of the microcap structures: 5a and 5b show field of microcap; 5c shows a microbolometer pixel included in a microcap

Electro optical performances

All electrical and electro-optical tests are defined and carried out with f/1 optical aperture, a background temperature of 300K, and FPA operated at room temperature. The video output allows the detector to be operated at 50Hz frame rate with 780kHz Master Clock and 67µs integration time. Among ROIC possibilities, CTIA gain has been set with Cint = 6pF. Figure 6a shows the responsivity histogram. The mean value is 3.25mV/K with dispersion as low as 2.10^{-2} mV/K. This very high responsivity uniformity is the result of the amorphous silicon technology behavior. The electrical dynamic range extends from 0.3V to 2.7V which corresponds to a temperature dynamic range at approximately 420K.
The average Noise Equivalent Temperature Difference (NETD) value of sensor presented in the figure 6b is equal to 95mK, measured at f/1 in front of a 27°C black body temperature.

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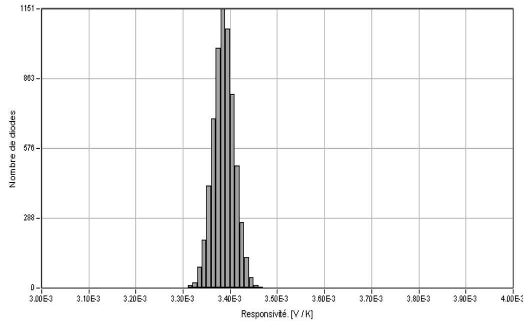


Fig. 6a. responsivity histogram [mV/K]

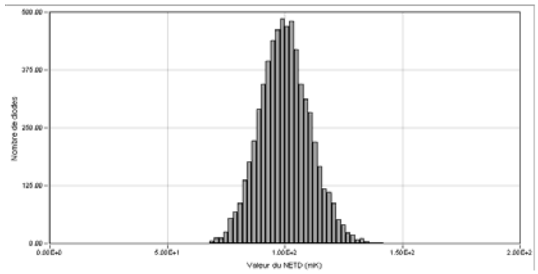


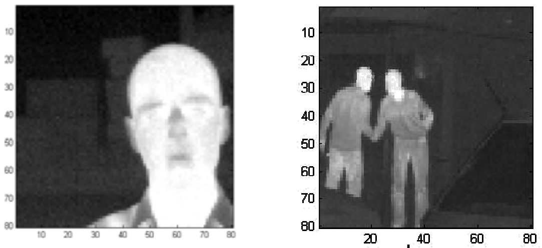
Fig. 6b. NETD histogram [mK]

Applications

With 6400 pixels in the array, Micro80P aims at improving next-generation motion detection systems, and increasing the measurement accuracy of building energy diagnostic tools, such as spot thermometers, and other commercial thermal equipment, thereby enabling to obtain more reliable data.

Designed to fill a capability gap in existing low resolution thermal detection sensors, Micro80P delivers data that goes several steps beyond the simple binary 'yes/no' response provided by single or quad element thermal detection sensors that are used in, for example, motion detectors. In addition to detecting motion, high spatial resolution of 80x80 pixels thermal sensor array – as shown in figure 7 - can also count, localize, as well as classify objects or human activity.

This means that Micro80P can be used to regulate HVAC by informing the system about the number of people present in a room or other elements present that could impact air temperature, such as the temperature of the walls, ground or ceiling. A resolution of 80x80 pixels is opening up a world of new possibilities for industrial, commercial and high volume imaging or non-imaging applications.



a b

Fig. 7. Thermal imaging scene recorded using an infrared camera with 25 mm f/1 optic: 7a: distance 1m; 7b: distance 10m

Conclusion

ULIS has developed a new generation of IR thermal sensor array, Micro80P, with optimized power consumption that meets the needs of smart detection and low resolution thermal imaging applications. Based on amorphous silicon, a microbolometer technology industry proven for its reliability, Micro80P has been designed to fill a capability gap in existing low resolution thermal detection sensors.

This IR sensor array offers the best tradeoff between performance and affordability thanks to innovative concepts implemented: a focal plane array of 6400 pixels, on-chip low power management system down to 5µW, NETD of 95mK, pixel level packaging technique compatibility.

Finally, Micro80P™ aims to provide efficient and reliable information to imaging and non imaging application, such as HVAC management or building energy diagnostic

References

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[i] Part of this development effort is done in MIRTIC project in cooperation with CEA/LETI (F), Schneider Electric Industries (F), Metaio GmbH (D) and ISD (GR), sponsored by the European ENIAC Joint Undertaking