New high resolution Thermopile Arrays for IR Imaging, person detection and consumer applications

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Introduction

Infrared arrays found their way into widespread applications in various industries. Due to increasing resolutions and decreasing costs, the growth rates for Infrared (IR) imaging sensors and cameras are assumed to continue having double-digit annual growth rates for the coming decade. Apart from that, the pandemic situation in 2020 and 2021 gave this technology a special boost with annual growth rates near 100 % compared to 2019 and before [1]. The simple technology of shutterless thermopile arrays could benefit in many large-scale "elevated body temperature" scanners, whereas thermal bolometers of VGA and higher resolution allowed measuring several persons in parallel respective the tear duct [2].
Unlike other array technologies, thermopile arrays allow to build true shutterless radiometric IR cameras or modules. The reason is, that thermopile arrays are DC sensitive devices and do not need to be biased. Thermopile arrays with pixel numbers from 8 x 8, 16 x 16, 32 x 32 resp. 32 x 24 and 80 x 64 were introduced to mass production for various consumer applications with pixel sizes of about 90 µm [3]. Array formats above 80 x 64 pixel or with smaller pixel sizes around 50 µm were so far clearly the domain of micro bolometers or other technologies.
In this paper, Heimann Sensor introduces first thermopile arrays with 60 and 45 µm pixel sizes allowing to extend the application range into higher density thermal imaging and lower cost security and surveillance application. All necessary signal conditioning and readout electronics including SPI interface are monolithically integrated on the sensor chip.

1 Sensor chip design and consideration

The new digital thermopile arrays are designed and fabricated in a special CMOS based MEMS technology using n type and p-type Poly silicon for the thermocouples.

Since the signal from the pixel naturally decreases with smaller pixel sizes, there are different options to maintain a good signal to noise ratio (SNR):

- The use of a special chip design with thermally isolated membrane from the Si heat sink by thin beams
- Reducing the heat conductivity of the gas around the pixel and
- Enhancing the fill factor by additional absorber structures (so called umbrellas!)

Figure 1 shows the principle of a thermopile array pixel with a thin reticulated membrane 4, which is suspended on two beams 3 between the silicon frame (substrate) 2. The beams 3 are carrying the thermoelectric sensitive materials n- and p-type poly-silicon as thermocouples. They are isolated by slots 7 from the membrane. The silicon frame is also acting as a heat sink. The hot junctions 9 are located on the suspended membrane and the cold junctions 8 are at the heat sink. The membrane is covered by an IR absorbing layer 4.

In **Figure 1 b)** such array pixel is depicted as cross sectional view. For enhanced signal the fill factor can be increased by adding an umbrella type radiation collector (as shown in **Figure. 2 c**), which shows the much bigger absorbing area of the umbrella compared to the area of the absorber on the membrane only.

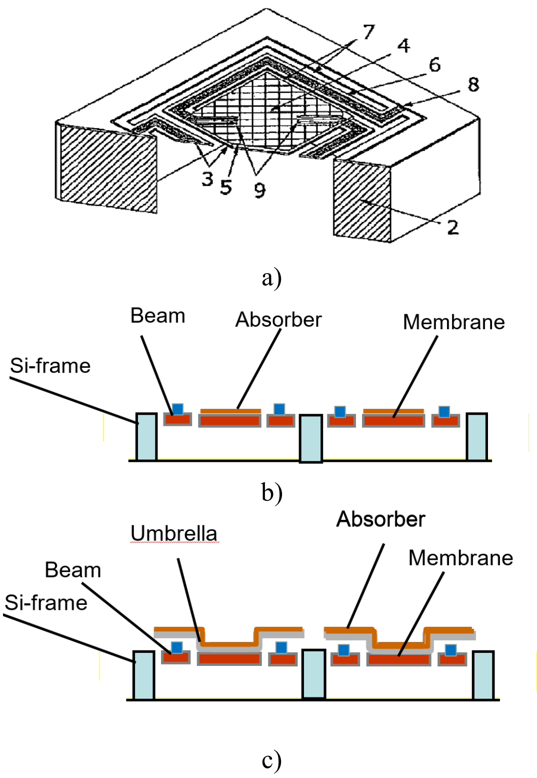

Figure 1: Thermopile array pixel with reticulated membrane, suspended on thin beams, a) in a 3D view, b) as cross sectional view with a normal absorber on the membrane and c) with additional umbrella type radiation collector covered with additional absorber layer.

The realization of thermopile pixels with absorber layer can be seen in Figure 2:

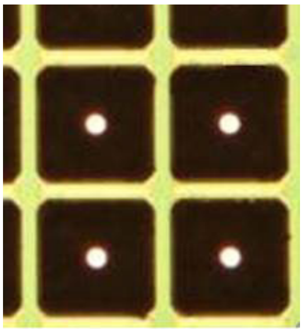

Figure 2: Thermopile array pixels covered by umbrella and absorber.

The newly introduced thermopile arrays with 60 µm and 45 µm pixels use a digital output via SPI interface to reach necessary high data and frame rates and reduce the number of necessary connections to 6-pin only. Thanks to integrated 16 Bit AD converters on-chip, the sensor arrays can be operated with frame rates around 9 Hz (full resolution), which can be extended for up to 20 …45 Hz and allow a very wide dynamic range with object temperatures up to 1000 °C.
All thermopile arrays and array modules are equipped with an infrared optical lens. These infrared optics are designated for the required field of view in the application. For instance the larger format arrays like 120 x 84 can cover a wide range of different viewing angles from 9-12 deg FOV for far distances and up to 120 x 90 deg FOV for ultra-wide field of view.
Higher resolution infrared arrays with such wide FOV of 120 x 90 deg are so far not reported.
Thermal images obtained from the 120 x 84 with 60 µm pixel size demonstrate its abilities for thermal imaging (see **Figure 3**).
The new 60 x 40 pixel array with 45 µm pixel size fits inside a standard TO-5 can (see **Figure 4**). So far, the highest pixel format fitting into TO-5 housing was 32 x 32.

2 Measurement results and thermal images

The new 60 x 40 arrays are mounted inside the TO-5 type housing. This contains besides the monolithic 60 x 40 chip also the necessary integrated data memory storage for calibration data of each pixels offset and sensitivity. 60 x 40 arrays can be operated at frame rates up to 45 Hz.
The typical power consumption of a calibrated 60 x 40 array of about 15 mW is well below the power consumption of low resolution bolometer arrays. That makes the 60 x 40 array module attractive for battery operated devices and saves power for applications with continuous operation and surveillance. Measured NETD values are around 50…100 mK @ 1 Hz.
Figure 3 shows a sample and thermal image of the new 60 x 40 array

The higher resolution 120 x 84 array is mounted inside a TO-8 type housing. These arrays reach frame rates of up to 20 Hz using an SPI-clock of 20 MHz.
The NETD of a vacuum packaged 120 x 84d array can reach 50 mK@1Hz@25°C with the latest pixel design and suitable optics. **Figure 4** shows thermal images obtained with 120 x 84 array modules.
Both 60 x 40 and 120 x 84 with special optics allow to measure temperatures up to 1000 °C and above.
In the following **Figures** we show thermal images taken with our application set using the highest resolution thermopile arrays with vacuum sealing:

Figure 3: 60 x 40 thermopile array chip mounted onto a TO-5 type header (left), assembled with an IR optics (center) and a thermal image taken with it (right).

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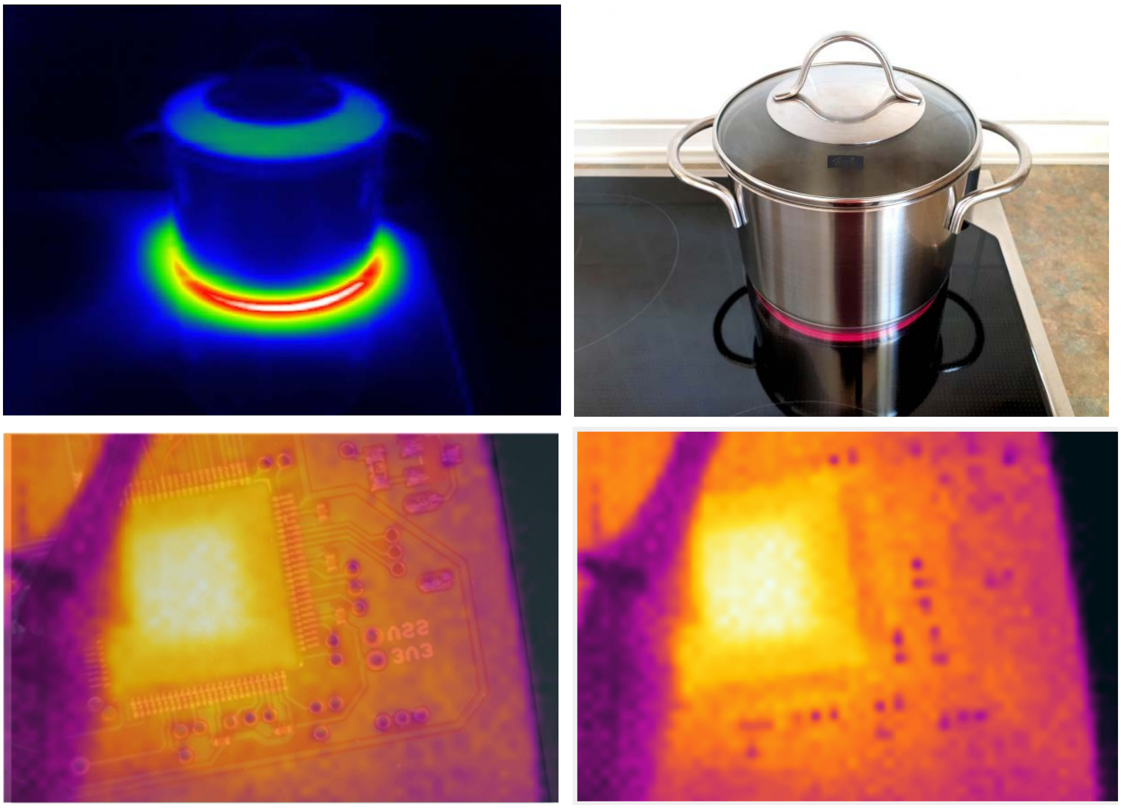

Figure 4: shows examples for thermal images created by the 120 x 84 array module with a cooking pot (above) and from a PCB in operation (below) without (left) and with a CMOS image overlay (right).

3 Literature

[1] Schieferdecker, J.; Schnorr, M., Forg. B.; Herrmann, F., Schmidt, C.; Leneke, W.; Simon, M., Wick, K: Elevated Body Temperature Screening with Thermopiles and other Thermal Sensors, Presentation, Uploaded oral presentation on SPIE DCS Conference on Infrared Technology and Applications XLVII, session SI-204-67, given April, 15, 2021.

[2] T. Hoelter, A. Kathman, A. Richards, M. Walters: Key Technology Trends and Emerging Applications for Compact Thermal Imagers, Proceeedings, Conference Sensor & Test, Nuremburg, 2015, p. 938.

[3] Schieferdecker, J.; Schnorr, M., Forg. B.; Herrmann, F., Schmidt, C.; Leneke, W.; Simon, M.: A new family of digital Thermopile Arrays for high volume applications; Proceedings Conference Sensor & Test 2019, Nuremburg, Germany.

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