A Miniature Low-Cost LWIR Camera with a 160x120 Microbolometer FPA

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ABSTRACT

This paper presents the development of a miniature LWIR thermal camera, MSE070D, which targets value performance infrared imaging applications, where a 160x120 CMOS-based microbolometer FPA is utilized. MSE070D features a universal USB interface that can communicate with computers and some particular mobile devices in the market. In addition, it offers high flexibility and mobility with the help of its USB powered nature, eliminating the need for any external power source, thanks to its low-power requirement option. MSE070D provides thermal imaging with its 1.65 inch^3 volume with the use of a vacuum packaged CMOS-based microbolometer type thermal sensor MS1670A-VP, achieving moderate performance with a very low production cost. MSE070D allows 30 fps thermal video imaging with the 160x120 FPA size while resulting in an NETD lower than 350 mK with f/1 optics. It is possible to obtain test electronics and software, miniature camera cores, complete Application Programming Interfaces (APIs) and relevant documentation with MSE070D, as MikroSens want to help its customers to evaluate its products and to ensure quick time-to-market for systems manufacturers.

Keywords: Thermal camera, microbolometer, MEMS, CMOS microbolometer, ROIC, low-cost thermal imaging, uncooled thermal imaging, infrared, LWIR, MSE070D, MS1670A-VP.

1. INTRODUCTION

Uncooled microbolometer type thermal imaging detectors are widely preferred in various military and civilian applications due to their advantages such as low-cost, low-weight, and low-power dissipation compared to their counterparts of the photon-based and cooled thermal detectors[1-9]. Legacy thermal imaging was mainly used in high-performance military and security surveillance applications. The uncooled and cooled infrared detectors that are used in these expensive systems provide best possible performance in terms of the noise equivalent temperature difference (NETD), frame rate, spatial resolution, and similar parameters. Associated detectors are driven mainly by increasing spatial video resolution and by decreasing pixel sizes. Due to rapid improvements in the microbolometer technology, the cost of the uncooled microbolometer detectors started to drop substantially. This rapid drop in the costs has fueled quick growth in several other markets that uses infrared thermal imaging technology. Including the legacy markets such as military and high-end commercial video surveillance and newly developing markets such as automotive and advanced presence detection, a variety of low-cost thermal imaging applications have emerged. The existing companies started to present smaller format detector arrays such as 80x80 or 80x60[10-12] to offer low cost infrared solutions for high volume consumer and automotive markets. However, there is a need for a paradigm shift in the uncooled microbolometer fabrication approach in order to reduce the cost drastically for satisfying the needs of very high volume markets.

The common approach for fabricating uncooled microbolometer focal plane arrays (FPAs) is to form thermally isolated and suspended detector pixels on top of a CMOS readout circuit monolithically by silicon micromachining, with post-CMOS fabrication steps. The major bottlenecks in decreasing the cost of the microbolometer type uncooled thermal detectors are the complexity and cost of the post-CMOS MEMS processes required for forming the detector structure and the vacuum packaging requirement of the sensor itself. MikroSens, as a fabless semiconductor company founded as a spin-off from METU-MEMS Research and Applications Center at the Middle East Technical University, has been developing unique techniques in order to simplify the detector fabrication processes while maintaining moderate detector performance. The detector implementation is achieved with one mask layer and simple post-CMOS fabrication steps, without requiring deposition of any high-TCR materials or complex post-CMOS fabrication steps that typically requires 8-15 masking steps. The approach of MikroSens allows to utilize wide range of wafer level vacuum packaging approaches, not only to decrease the production cost but also to allow the use of wafer level vacuum packaging

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approaches used in the mass production by high-volume production foundries, in order to be able to address the needs of the rapidly growing value performance infrared imaging market. MikroSens' vision is to be the leader of low-cost commercial infrared technology with a comprehensive product portfolio, which will help enabling many new infrared imaging applications in automotive, advanced presence detection, security, and even consumer electronics. This paper introduces a miniature thermal camera MSE070D that uses a low-cost 160x120 CMOS-based microbolometer FPA (MS1670A-VP) as the thermal sensor. MSE070D is USB powered, can communicate with computers and some particular mobile devices, and weighs only 15 grams without lens, which provides great flexibility and mobility.

2. MINIATURE THERMAL CAMERA

MikroSens develops miniature thermal camera cores and modules as well as custom test electronics and test software. Figure 1 shows MSE070D miniature thermal camera with two different lenses and Table 1 summarizes the technical specifications. The overall camera module covers 1.65 inch-cube volume and weighs only 15 grams excluding the lens. Two different lenses provide different field of view and F-numbers for different imaging applications. MSE070D miniature thermal camera uses MS1670A-VP as the thermal sensor which will be described in the next chapters.

(a) (b)

Figure 1: The photographs of MSE070D miniature thermal camera with (a) f/1.2 optics and (b) f/1.0 optics.

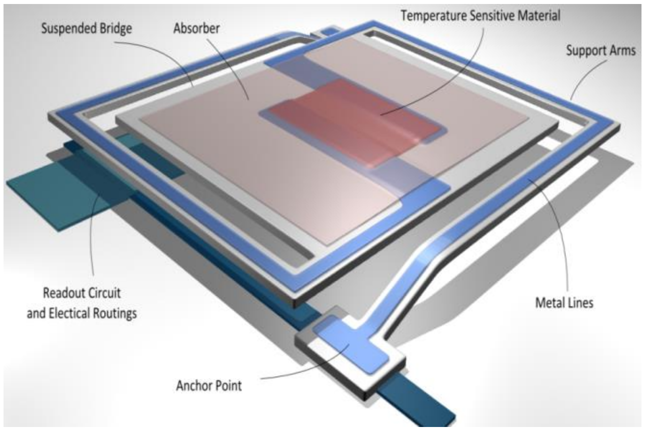
Table 1: Technical specifications of MSE070D miniature thermal camera module.

Dimensions	1.2" x 1.2" x 1.2" (not including lens)
Weight	~ 15 gr (not including lens)
Power Source	USB powered
Power Dissipation (including MS1670A-VP sensor)	< 625 mW (fast mode, compatible with computers, provides 30 fps frame rate) < 350 mW (slow mode, compatible with mobile devices, provides 9 fps frame rate)
Image Processing Capability	One point non-uniformity correction and similar processing capabilities
Provided Digital Interface	USB data; serial ADC output with synchronization signals, or CMOS FIFO interface for OEM development

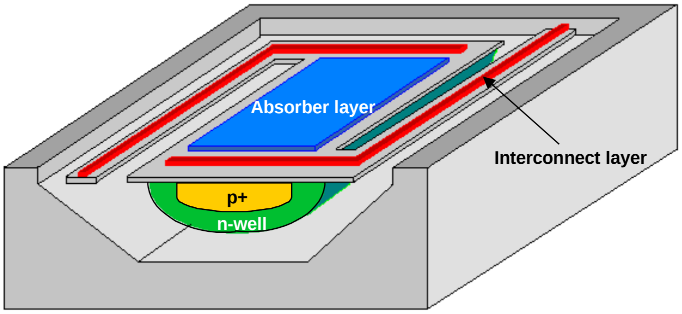
The camera module contains power regulators, analog-to-digital converters, a low power and small form factor FPGA, and a USB communication interface. In order to help OEM development, MSE070D also provides raw thermal video data via serial and parallel CMOS signals together with synchronization signals that can be used by third party electronics. The included low-power and small form-factor FPGA performs several image processing functions, such as one point non-uniformity correction. MSE070D miniature thermal camera can operate in two different modes; i) fast mode where it provides 30 fps thermal video and dissipates 625 mW electrical power, and ii) slow mode where it provides 9 fps thermal video and dissipates 350 mW electrical power. When connected to mobile devices, the miniature thermal camera is operated in slow mode in order to stay in the mobile device USB power budget. Documentation and software of the camera module is provided by MikroSens to enable quick and easy evaluation by its customers. The company also provides an API and related documentation in order for the customers to develop their own applications.

3. SENSOR TECHNOLOGY

Thermal or uncooled infrared detectors sense the change in an electrical parameter with change in the device temperature related to the amount of absorbed infrared energy. The thermal or uncooled microbolometer type thermal detectors are usually built monolithically with a CMOS readout integrated circuit with the use of the MEMS technology. There are basically two different approaches: surface micromachining and bulk micromachining. Figure 2 shows a simplified illustration of a traditional surface micromachined microbolometer type uncooled thermal detector and a bulk-micromachined type uncooled microbolometer. In both approaches, each pixel is formed by a suspended bridge that is thermally isolated from the substrate. An absorber layer on the bridge absorbs the incoming infrared radiation, causing a temperature increase of the suspended bridge structure. This temperature increase is sensed with the help of a temperature sensor. The temperature sensor in surface micromachined microbolometers are usually selected as a resistor implemented with a special material with a high TCR parameter. Although other materials are also tried, there are two special materials mostly used for this purpose in the industry, VOx and a-Si. The general trend is to fabricate these detector arrays in the in-house fabs of the companies or in dedicated foundries, as these materials are special materials. Besides, these materials limit the wafer level vacuum packaging options, as they are sensitive to temperatures above 300ºC, preventing the use of the bonding techniques developed by high volume production foundries for other high volume MEMS products, such as accelerometers and gyroscopes. Also, surface micromachined microbolometers are produced with a post-CMOS process typically requiring 8-15 masking steps, which not only increases the fabrication cost, but also decreases the production yield.



(a)



(b)

Figure 2: (a) A simplified illustration of a typical surface micromachined microbolometer type uncooled thermal detector where a specifically optimized active material is grown on top of an thermally isolated bridge. Since the bridge is thermally isolated from the substrate, the absorbed infrared radiation causes a temperature increase and the active material is used as a temperature sensor to sense and measure this temperature increase. (b) Perspective view of the bulk-micromachined microbolometer that can be obtained in a standard CMOS process[13].

MikroSens has been developing unique microbolometer fabrication technologies in order to simplify the detector fabrication process, based on the microbolometer technology that has been developed at METU-MEMS Center of Middle East Technical University. The developed technologies mainly focus on simplifying the detector fabrication by decreasing the number of lithography steps and layer depositions. Figure 3 shows a simplified illustration of an example microbolometer fabrication process developed by MikroSens. This process is an ultimate case as (i) only one mask process step is required; (ii) no deposition step is used since the CMOS devices are used as the temperature sensing active material[13-21]. The silicon beneath the detector bridge is etched in order to thermally isolate the detector bridge. Although the use of a CMOS component as the active material instead of a non-CMOS and highly sensitive one limits the detector performance, the detector fabrication cost is significantly reduced as the overall MEMS process contains no critical lithography or deposition as opposed to surface micromachining microbolometer approaches.

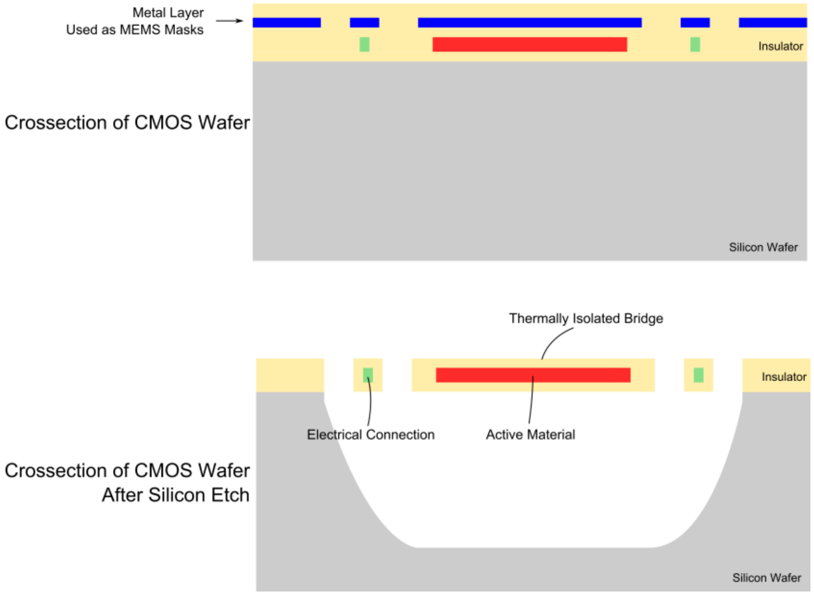


Figure 3: A simplified illustration of an example microbolometer fabrication process developed by MikroSens. This process is an ultimate case as (i) only one mask process step is required; (ii) no deposition step is used since the CMOS devices are used as the temperature sensing active material[13-21]. The silicon beneath the detector bridge is etched in order to thermally isolate the detector bridge.

4. SENSOR FEATURES

Table 2 summarizes the technical specifications of MS1670A-VP uncooled thermal sensor. The sensor die covers 17.1mm x 15mm silicon area on 6” CMOS wafers and contains a 160x120 microbolometer type uncooled thermal detector focal plane array with 70 µm detector pitch. Although the detectors are sensitive to a wide spectral range, they are optimized to have highest sensitivity at 8-12 µm spectral range. The scan rate is adjustable and can be increased up to 30 fps. The power dissipation of the sensor is less than 50 mW at 30 fps frame rate.

The microbolometer type uncooled thermal detectors need vacuum environment because they need to be thermally isolated from the substrate. The vacuum packaging is usually done either at the die level or at the wafer level. Although die level vacuum packaging is simpler in terms of technology development, the cost of the die level vacuum packaging is much more than the cost of the thermal sensor itself. Furthermore, the production process does not allow ramping up to full production at high volumes. Wafer-level vacuum packaging, on the other hand, is better suited for mass production and hence decreases the overall cost of the system.

Figure 4 shows the photograph of an MS1670A-VP die that is wafer-level vacuum packaged at high-quality and with a long life vacuum level. The cap wafer is highly transparent with better than 90% transitivity in the 8-12 µm spectral range, as an option for high performance applications. The embedded getter into the package provides long-term high quality vacuum environment.

Table 2: Summary of the technical specifications of MS1670A-VP uncooled thermal sensor.

Detector Related	FPA Size	160 x 120
	Detector Pitch	70 μm x 70 μm
	Spectral Range	Wide-band detector structure, limited to 8-12 μm with appropriate filter
ROIC Related	Supply Voltage	5.0 V (between 4.9 V and 5.5 V)
	Power Dissipation	< 50 mW (at 30 fps frame rate)
	Number of Outputs	1 analog output
	Output Voltage Swing	3 V
	Voltage Swing for Digital Signals	0 – 5V
	Programming Interface	3-wire SPI
	Timing and Configuration	On-chip programmable sensor timing and configuration
	Integration Time	Programmable, up to 100 μs at 30 fps
	Integration Capacitance	Programmable, up to 30 pF
Packaging Related	Die Size	17.1mm x 15mm
	Vacuum Package Technology	Wafer-level vacuum package
	Vacuum Package Transitivity	Option 1: > 90%; Option 2: >70%; for 8-12 μm band
Performance	NETD	< 350 mK with f/1 optics at 30 fps frame rate

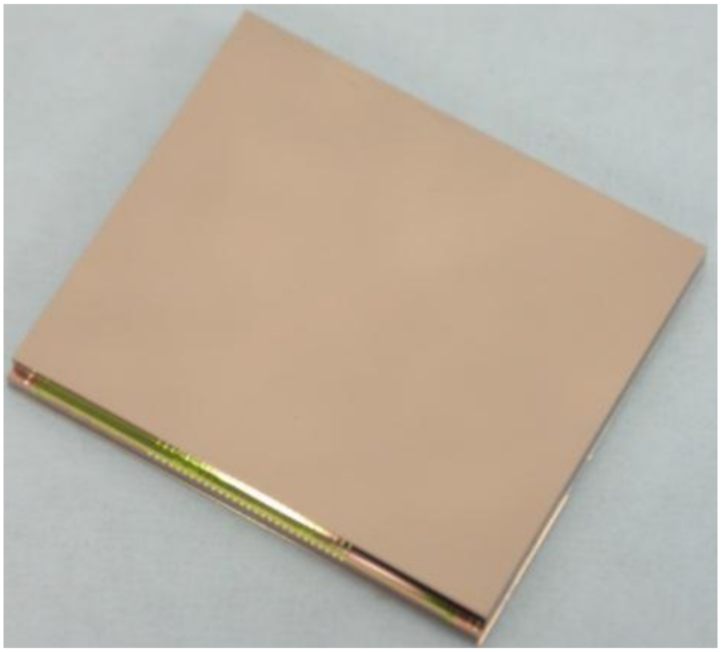


Figure 4: The photograph of MS1670A-VP vacuum packaged uncooled thermal sensor.

5. ROIC ARCHITECTURE

Figure 5 shows the simplified block diagram of MS1670A-VP uncooled thermal sensor readout integrated circuit (ROIC). The detector signals are processed by the column level analog signal processing blocks and they are multiplexed to output in sequential order. MS1670A-VP is highly configurable via 3-wire serial programming interface. The ROIC operates with 5 V power supply and dissipates less than 50 mW at 30 fps frame rate.

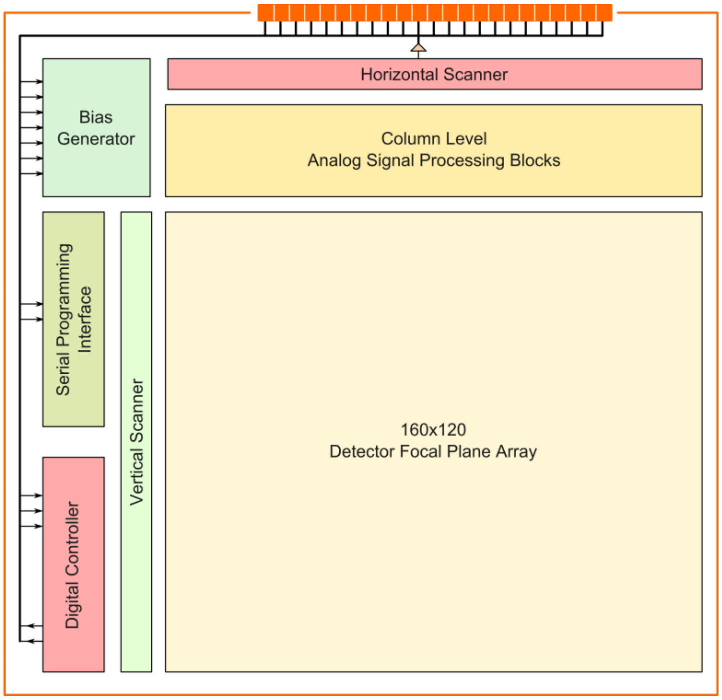
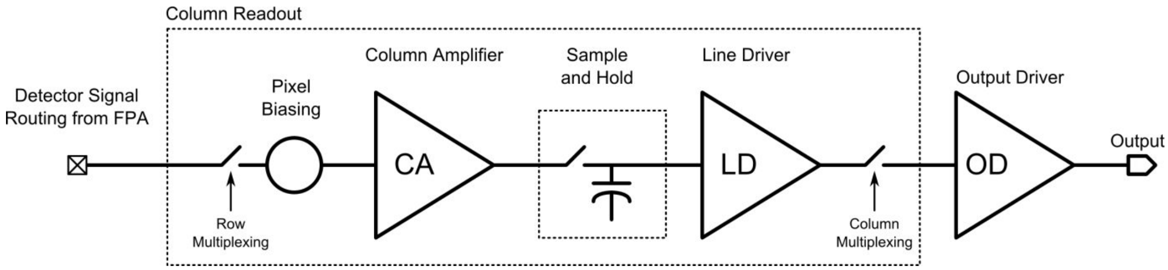


Figure 5: The simplified block diagram of MS1670A-VP uncooled thermal sensor.

Figure 6 shows the simplified block diagram of the analog signal flow of MS1670A-VP uncooled thermal sensor. The detectors in the 160x120 focal plane array are multiplexed and biased by the pixel biasing circuitry. The detector signal that contains the infrared induced signal is amplified by the column amplifier and stored by the sample-and-hold circuit. The stored signal is buffered by the line driver and multiplexed to the output node. MS1670A-VP contains multiple column readouts in order to process the detector signals in parallel. The output of the line drivers are multiplexed to the output driver, which forms the analog video output of the sensor.

The detector bias configuration and the column readout gain are programmable via the 3-wire SPI of the sensor. Adjusting the column readout gain is necessary especially when the sensor is used in large dynamic range applications. It is possible to adjust the readout gain differently between the frames, which enables the capture of multiple gain images. Fusion of these multiple gain images results in high dynamic range infrared images.



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6. FIRST DEMONSTRATIONS

Figure 7 shows some sample snapshot infrared images obtained by MSE070D miniature thermal camera where only one-point uniformity correction is applied. With some room to improve, MSE070D provides an unparalleled value performance with its ultra-low fabrication cost.

Figure 7: Sample infrared snapshots obtained from MS070D miniature thermal camera.

7. SUMMARY AND CONCLUSIONS

This paper reports the development of a miniature thermal camera MSE070D that provides 30 fps thermal video with a 160x120 spatial resolution. MSE070D uses a low-cost thermal sensor MS1670A-VP that is a vacuum packaged, microbolometer type thermal sensor, developed in order to provide moderate performance with very low production cost. Mikrosens' MSE070D miniature thermal camera provides 350 mK NETD with f/1.0 optics. MikroSens also offers test electronics and software, miniature camera cores, complete APIs, and relevant documentation in order to help customers evaluate MikroSens products and ensure quick time-to-market for systems manufacturers. Currently, MikroSens also develops new technologies and products targeting value performance infrared imaging applications, reducing the production costs even further down.

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