Recent development of small pixel uncooled focal plane arrays at IRay

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***Abstract*—Small pixel microbolometer technology has shown dramatic improvements in uncooled infrared focal plane arrays in recent years. The uncooled microbolometer makers have transitioned through smaller pitches about every six years while maintaining a noise equivalent temperature difference (NETD) of 20-50mK. IRay commercialized 25µm pixel pitch 640×512 and 384×288 uncooled infrared focal plane arrays (IRFPAs) and 20µm pixel pitch 640×512 and 384×288 IRFPAs in the past five years. Vanadium oxide (VOx) microbolometers incorporated in these products is depicted in this paper. A 17µm pixel pitch 640×512 uncooled IRFPA with NETD of less than 35mK is also presented. The detectors are designed to enhance its manufacturability, life time, and its reliability under shock and vibration to meet security applications and Driver's Viewer Enhancer (DVE) requirements.**

I. Introduction

VANADIUM oxide microbolometer infrared focal plane arrays (IRFPAs) have been employed in a wide range of thermal imaging applications, such as medical imaging, thermography, night vision, firefighting, surveillance, predictive maintenance and industrial process control [1]. Uncooled IRFPAs based on smaller pitch microbolometers has attracted increasing research interest worldwide during the past few decades [2]. Demonstration of 17µm microbolometer technology [3] opens the door to a new generation of smaller, lighter, and lower cost hand-held and vehicle mounted uncooled systems. Smaller pixel pitch IRFPAs allow camera designers to use smaller optics without compromising the system performance thus reducing the overall camera weight, size, power and cost [4]. CEA-LETI demonstrated 12µm microbolometers on 17µm ROIC in 2012 [5]. BAE Systems commercialized its 12µm camera core in 2014. DRS Technologies Inc. announced in April 2015 that its highly anticipated 10µm pixel pitch infrared detector has been successfully demonstrated to select defense industry prime contractors.

In this paper, we presented the microbolometer technology incorporated in 25µm and 20µm pixel pitch VGA and QVGA format IRFPAs. The detectors are designed to enhance its manufacturability, life time, and its reliability under shock and vibration to meet security applications and Driver's Viewer Enhancer (DVE) requirements. A 17µm pixel pitch 640×512 uncooled IRFPA based on double sacrificial layer microbolometer is also presented.

II. Microbolometers

IRay commercialized VGA and QVGA format IRFPAs with single level 25 µm pitch microbolometer in 2013. The 25µm microbolometer incorporates single layer sacrificial layer technology with vanadium oxide thin films. The IRFPAs features less than 35mK NETD with f/1.0 optics over 8-14µm spectrum.

The microbolometer structure has been described in detail in many papers [6, 7]. Microbolometer arrays are fabricated on silicon readout integrated circuit (ROIC) wafers using surface micromachining technique. The microbolometer consists of a microbridge, suspended above the underlying ROIC wafer, which is typically supported by two [8] or four [9] narrow legs for thermal isolation. VOx was selected as the bolometer

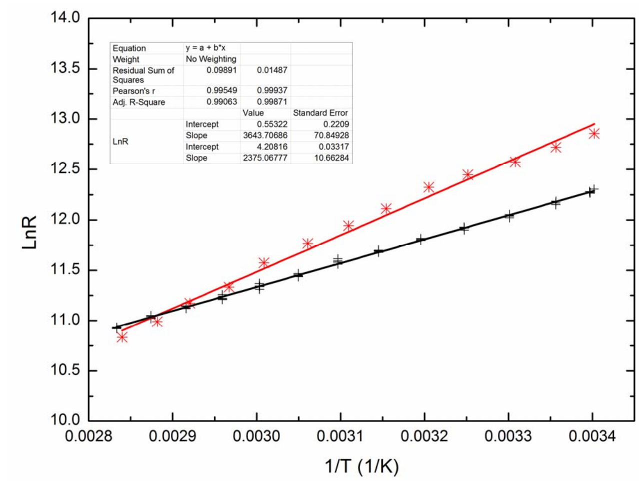

Fig. 1. Typical sheet resistance vs. temperature relation of VOx thin films.

material due to its combination of high thermal time constant (TCR), acceptable electrical resistivity, low flicker noise coefficient, and fabrication compatibility [10]. VOx thin films with wafer level 1σ non-uniformity of less than 1.5% and TCR of from -2.64% /K to -4.04% /K have been developed for IRFPAs fabrication. Typical sheet resistance vs. temperature relation is shown in Fig. 1.

The 25 µm pixel design and technology was scaled down to

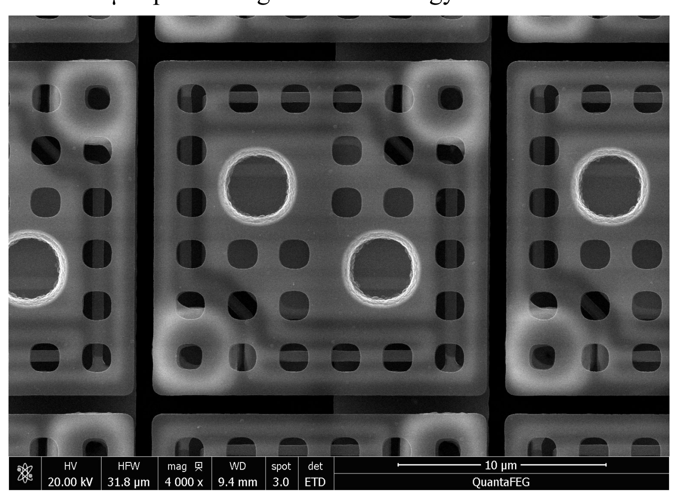

Fig. 2. SEM photograph of 17µm microbolometer

20 µm pixel pitch, based on which two categories of products are now in volume production. However, it requires improving several key fabrication technologies to successfully carry out a 17 µm pixel pitch microbolometer. Among these were reducing layer thickness, reducing pixel leg dimensions, reducing the

size of microbridge post and contacts, and developing a double layer fabrication process. 17μm microbolometers depicted herein are based on a 0.35μm MEMS production line with double sacrificial layer technology. The SEM photograph of 17μm microbolometer is shown in Fig. 2. Typical thermal time constant of such microbolometer is 10ms.

Since emissivity is directly proportional to pixel responsivity,

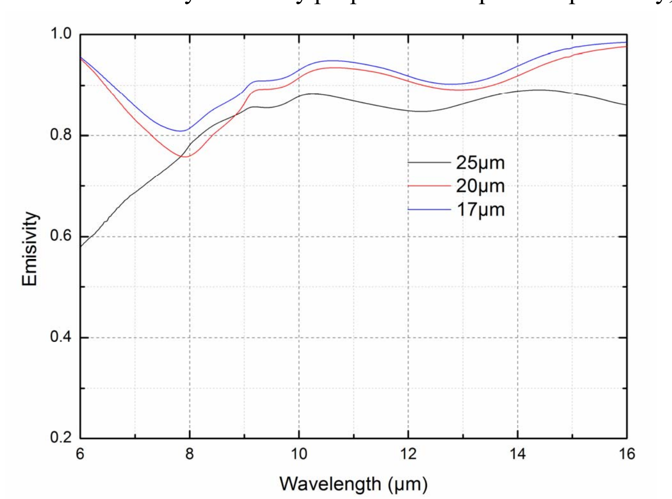

Fig. 3. Emissivity spectrum of microbolometers with different pixel pitch.

emissivity of 17μm microbolometers was optimized with HFSS simulation by adjusting the two air gaps as well as the perforation in the top platform. Emissivity of microbolometers, as shown in Fig. 3, was measured by using FTIR spectrometer in conjunction with high performance infrared microscope.

III. IRFPAs Evaluation

The IRFPAs were packaged in metallic vacuum housing with Germanium infrared window to maintain vacuum pressure of less than 0.1 Pa for radiometric evaluation [11]. The 25μm, 20μm, and 17μm pixel pitch VGA and QVGA format IRFPAs feature less than 35mK NETD (@300K, 50Hz, f/1.0) over 8-14μm spectrum at 300K ambient temperature. Typical NETD histogram of 20μm IRFPAs is shown in Fig. 4. Good thermal image, as shown in Fig. 5, is feasible with such low NETD.

With double sacrificial layer microbolometer technology,

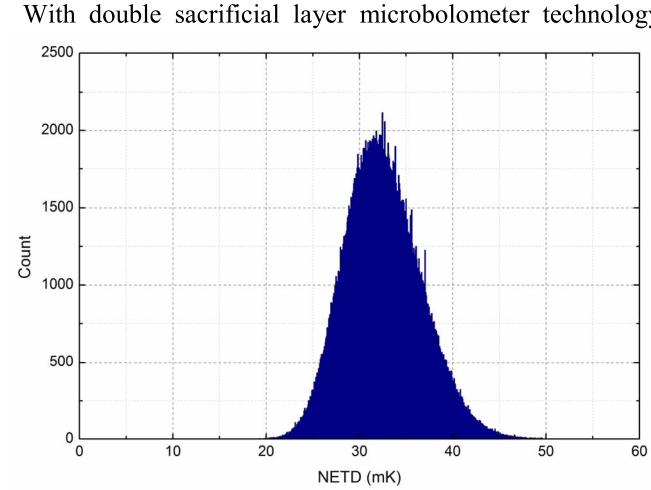

Fig. 4. 20μm 640×512 uncooled IRFPA original output histogram.

NETD of 28.9mK is achieved. However, without integrating the second platform, the best achieved NETD of 17μm 640×512 uncooled IRFPAs is only 37.9mK.

Radiometric performance of 17μm 640×512 uncooled

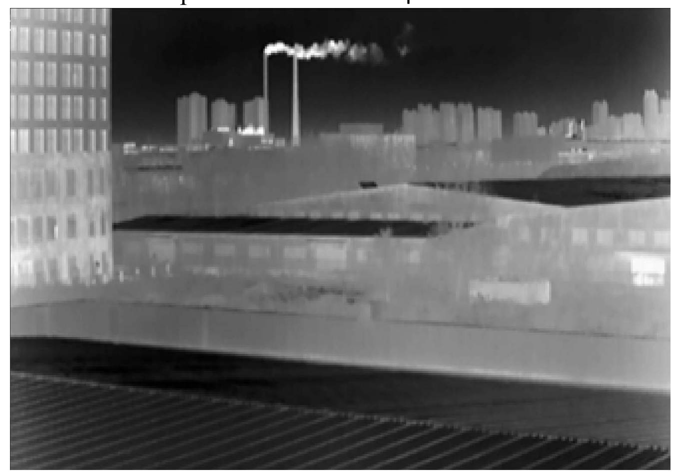

Fig. 5. Thermal image taking with 20μm 640×512 uncooled IRFPAs.

IRFPAs over -40°C~+85°C operation temperature is presented in Fig. 6. The IRFPAs was configured to low gain mode to get good signal transfer function (SiTF) and NETD dispersion over operation temperature.

Fig. 7 shows an infrared image taking with the 17μm

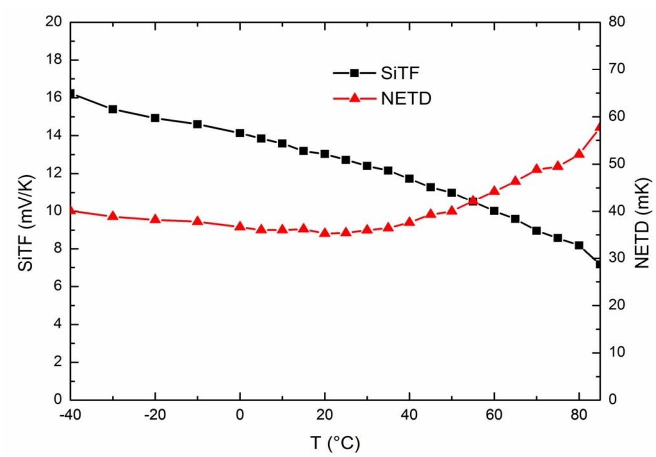

Fig. 6. Radiometric performance of 17μm 640×512 uncooled IRFPAs over -40°C~+85°C operation temperature.

Fig. 7. Thermal image taking with 17μm 640×512 uncooled IRFPAs.

640×512 IRFPAs without using TEC for IRFPA temperature regulation. The evaluation results suggest that the IRFPAs are compatible with TEC-Less operation. Compared to Fig. 6 the spatial resolution of 17μm 640×512 uncooled IRFPAs is better than 20µm IRFPAs.

IV. DVE Applications

High temperature storage, low temperature storage, thermal shocks, temperature cycling, random vibration, and mechanical shocks reliability testing according to MIL-STD 810F and MIL-STD 883H were performed to evaluate the IRFPAs. The reliability testing results suggest that the IRFPAs meet DVE requirements [12]. A DVE is developed with 20µm 384×288 IRFPAs.

Fig. 8. Thermal image taking with 20µm 384×288 IRFPAs compared to visible image.

Fig. 8 presents the thermal image taking with IRay's DVE.

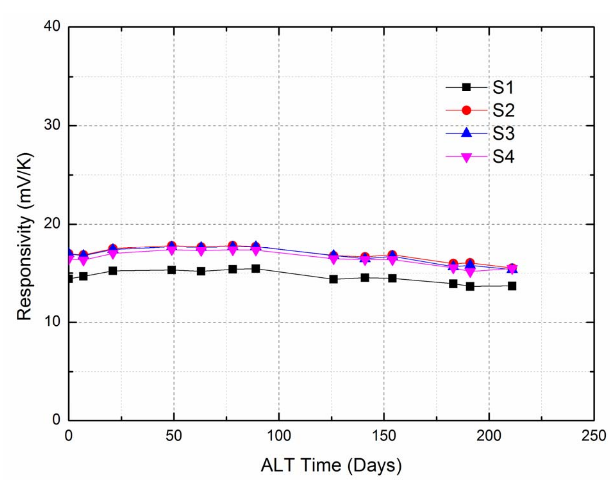

Fig. 9. Accelerated life time testing of 25µm 384×288 uncooled IRFPAs.

Compared to the visible image shown in Fig. 8, drivers' visual perception can be extended. The DVE products based on 17µm 640×480 IRFPAs are under development.

Accelerated life time testing of 25µm 384×288 uncooled IRFPAs has been ongoing. Fig. 9 illustrates the test data on the IRFPAs. The samples were baked at 70°C and checked weekly at room temperature for changes in responsivity. The data show little degradation after 210 days of bake. This should ensure more than 15 years of life time at 20°C ambient temperature [13].

V. Summary

This paper presents IRay's microbolometer technology and the application of 25µm, 20µm, and 17µm pixel pitch VGA and QVGA format IRFPAs. The IRFPAs features less than 35mK NETD. Reliability testing shows that the IRFPA products meet the requirements of security applications and DVE. Development of 12µm IRFPAs is currently underway.

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