FABRICATION OF VANADIUM OXIDE MICROBOLOMETERS ON THIN POLYIMIDE FILMS

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ABSTRACT

We report the fabrication and characterization of thin film vanadium oxide microbolometer detector elements on thin (12.5 um) polyimide films. The microbolometer detectors have been designed and are being evaluated for use in scanning radiometers aboard a satellite. Preliminary characterization results (nominal resistance, temperature coefficient, thermistor noise) are reported.

KEYWORDS

Thermal sensors, microbolometers, polyimide, thin film technology

INTRODUCTION

Uncooled vanadium oxide microbolometer arrays are currently quite common, commercially available and used as digital infrared imagers; they are typically fabricated using silicon micromachining techniques and often times integrated with CMOS technology. In a scanning radiometer on the other hand, a scanning optical system directs infrared light through an aperture to a single detector element, which can be relatively large (e.g. millimeter sized). These single detector elements are optimized for sensitivity, broadband response and thermal mass. In this paper, the fabrication of thin film microbolometer detectors for use in a scanning radiometer system aboard a satellite is discussed. These detectors have been designed and are being evaluated for use in the NASA CERES (Clouds and Earth's Radiant Energy System) mission [2]; in this mission, the interactive role of cloud and radiation feedback in the Earth's climate system is investigated using scanning radiometers. The proposed detectors are 1.5 x 1.5 mm in size and the thin film fabrication process promises to both reduce cost and improve performance, in comparison with the legacy detectors which have been assembled in a highly serial manufacturing process.

In most microbolometers the detector elements (thermistors) are thermally insulated from their environment by micromachining thin membranes or cantilevers on which the thermistors are located, hereby greatly reducing thermal losses through conduction and enabling high responsivity. Instead of relying on thin micromachined membranes to provide thermal insulation from the substrate, our approach consists of fabricating thermistors on thin (12.5 um), thermally insulating polyimide substrates. Besides simplicity and low cost, this approach results in more robust and reliable devices, of utmost importance in space missions. The main challenge is to produce high quality and high sensitivity thermistors on these thin polyimide films, as they are non-planar, imperfect and porous substrates. This paper focuses on the fabrication techniques used to build the detectors, and also presents electrical characterization results. For more information on the optical system and application, we refer to [2] and [3].

DESIGN AND FABRICATION

Figure 1 shows schematic cross-sectional and top views of the proposed detectors.

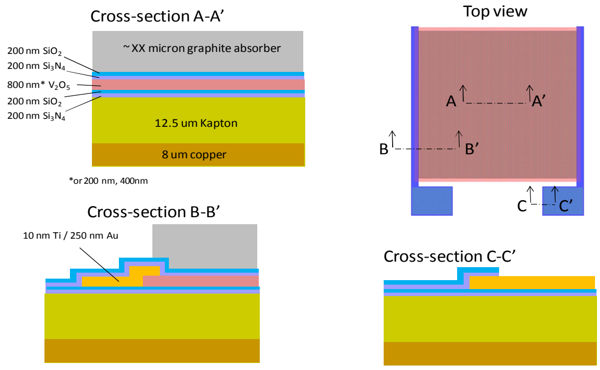


Figure 1: Schematic cross-sectional (top left, bottom left and right) and top views (top right) of the microbolometer element; overall size is 1.5mm x1.5mm, total thickness ~30um; the dimensions are not to scale.

The polyimide film is coated on its backside with 8um of electroplated copper; the copper layer - under compressive stress - increases the planarity and rigidity of the film and also serves as thermal interface/contact layer, used to control the temperature of the detector at equilibrium. The thermistor material (vanadium pentoxide) is deposited on the front side, as are a set of passivation and interconnect layers. An absorption layer (of variable thickness, typically ~10um) is deposited on top of the thermistor layers. The fabrication process sequence is illustrated by Figure 2; the process is based on technology previously employed to realize miniaturized calorimeters [4].

The copper clad polyimide film is initially laminated onto stainless steel 'picture frame' type fixtures using chemically inert epoxy resin (an Epon™ blend), which are then further processed. All steps are performed at relatively low temperatures (<200 °C); a set of barrier layers (each consisting of a stress compensated bi-layer of SiO/SiN, deposited on the polyimide film in a PECVD reactor) encapsulates the vanadium pentoxide layer, which is reactively sputtered in a mixed argon/oxygen atmosphere with a DC magnetron sputtering system [5]. The barrier layer is critical to protect the thermistor from the environment (water vapor, gases) and prevent excessive 1/f thermistor noise. Electrical contacts to the thermistor are created using an evaporated titanium/gold layer, patterned by lift-off. In all described thin-film process steps, stress control is critical in order to prevent deformation of the substrate and cracking or delaminating of the films.

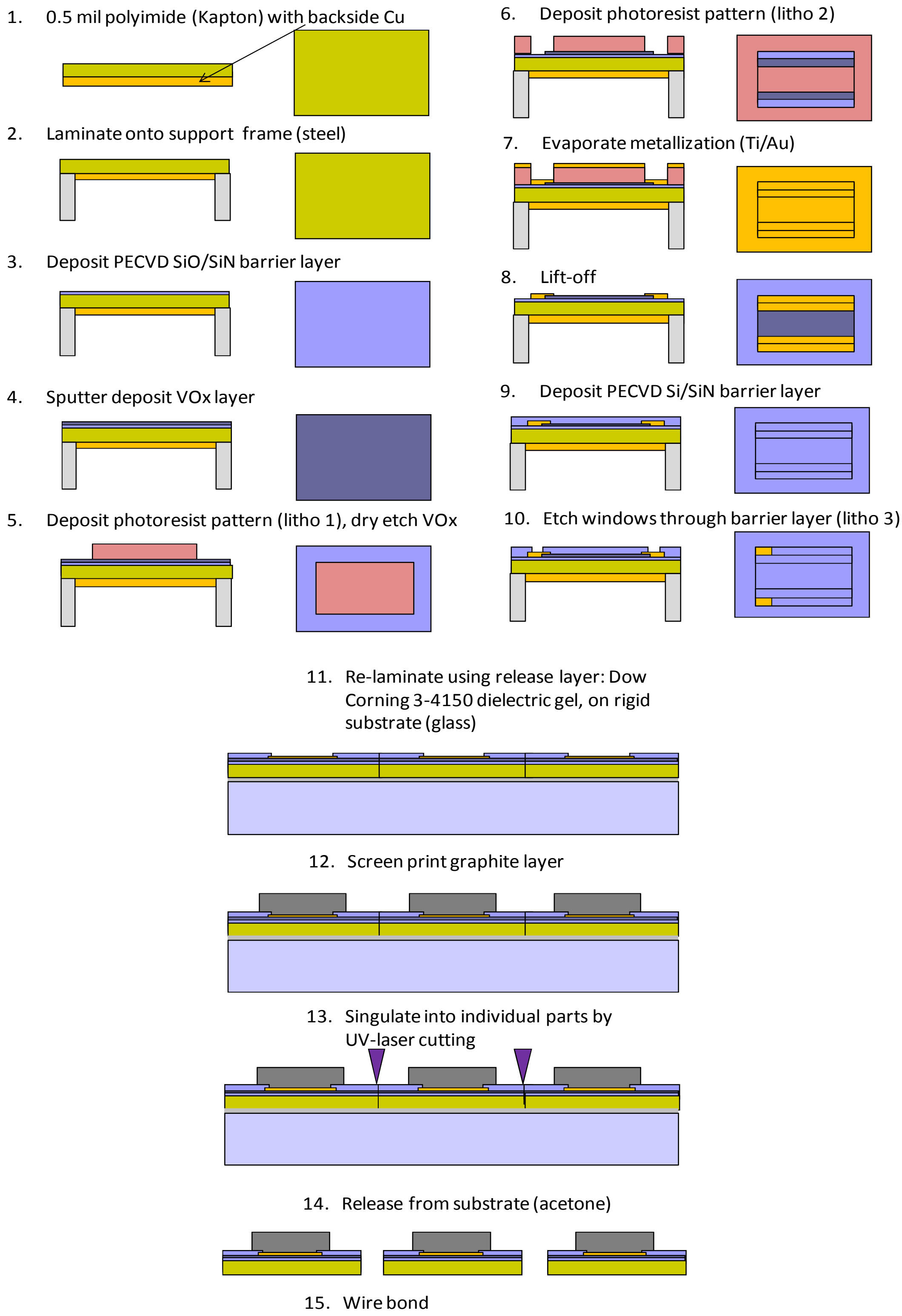
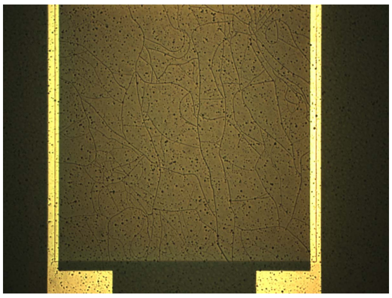
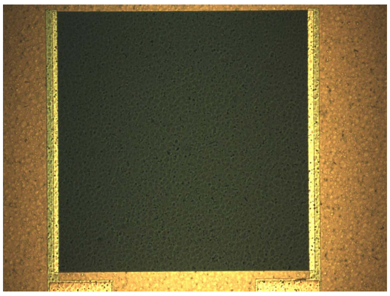


Figure 2: Schematic fabrication process sequence.

The backside copper layer in particular – under compressive stress – plays an important role in that it puts the polyimide film under tensile stress. This tensile stress is maintained throughout the fabrication process and all its temperature excursions, and prevents excessive strain and cracking of the thin inorganic films deposited on the top side. To illustrate this, Figure 3 shows a micrograph of an experimental fabrication run where no backside copper is used (a), and compares it to one where the copper is present (b). Thin hairline cracks in the vanadium oxide layer are clearly visible in (a). On the (a) samples highly non-uniform nominal resistance values are observed and measured 1/f noise is much higher than in the (b) samples.



(a)



(b)

Figure 3: Comparison of process without backside copper (a) to process with backside copper (b). Samples are illuminated from the back.

After deposition and patterning of the top barrier layer (PECVD SiO/SiN bi-layer), windows are etched through this layer to expose the contact pads (step 10 in Figure 2). Next, the polyimide film is relaminated onto a glass substrate, and released from its stainless steel processing frame (step 11). The adhesive used in this step is Dow Corning's 3-4150 dielectric gel, as it provides a low-tack adhesive film which allows for relatively easy singulation of the devices at the end of the process.

An infrared absorber layer is deposited on top of the thermistor area using screen printing of a graphite ink (Electrodag 423SS, supplied by Henkel); different thicknesses have been prepared, a typical value is ~10um. Alternatively, a layer of Aeroglaze Z306 (a much lower viscosity ink, supplied by LORD Corporation) may be selected and deposited using a stencil, as it has slightly superior absorption characteristics. Both materials approximate an ideal black body material.

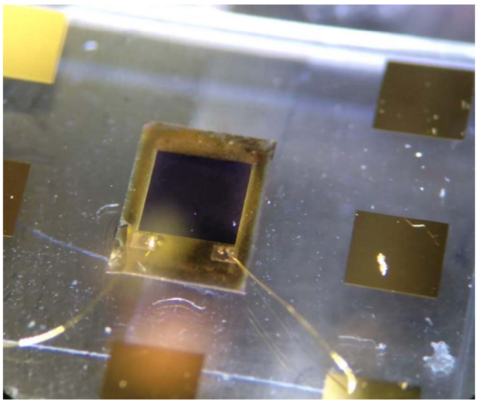


Figure 4: Singulated device under test, mounted on glass substrate and contacted with thin gold wire bond leads.

Individual devices are singulated using a 265nm UV laser and subsequently characterized. Emulsitone 1146, supplied by the Emulsitone Company, is used as protective coating. The singulated devices are cleaned by immersion in hot water (dissolving the water-soluble Emulsitone), followed by warm (~40C) acetone and isopropyl-alcohol to remove residue from the 3-4150 gel. Figure 4 shows a singulated device-under-test, and Figure 5 shows an entire array of devices prior to singulation.

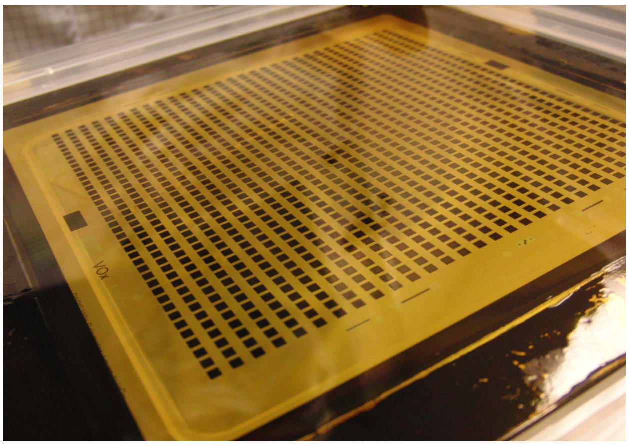


Figure 5: Microbolometer array prior to singulation; each dark square area is a single detector element.

RESULTS

Table 1 summarizes some of the data. Thermistor resistance was measured on 15 samples originating from different locations on a single array wafer; temperature coefficient of resistance was measured in a temperature-controlled chamber; thermistor noise (expressed as an equivalent temperature difference) was measured by connecting the device under test with three matched metal-film resistors in a Wheatstone bridge configuration, with the output signal amplified and read out using a Stanford Research Systems SR850 digital lock-in amplifier (Figure 5). The Wheatstone bridge is fed an AC-voltage of about 250 mV at 1 kHz, synchronized with the reference oscillator signal from the lock-in amplifier, which has its low-pass filter cut-off frequency set at 4.2 Hz and integration time set to about 30 seconds. This results in a clean signal not contaminated by amplifier or electronics noise, allowing measurement and analysis of the thermistor noise and noise sources (see Figure 6), in particular in the low-frequency range of interest, where 1/f noise can be an issue.

Quantity	Value
TCR (%/K)	0.030 ±.002
R (K)	137.8 ± 0.1
CV on R	13%
rms thermistor noise (mK)	0.150 ± 0.05

Table 1: measured data: TCR (temperature coefficient of resistance), R, coefficient of variation on R (sample size is 15), and thermistor noise (expressed as a noise-equivalent temperature difference).

The total noise number of ~0.150mK (expressed in noise-equivalent temperature, corresponding to about 560 nV integrated over the given bandwidth) is comparable to the results obtained on encapsulated vanadium oxide films on planar silicon or glass substrates. This suggests that the microstructure of the vanadium oxide on the polyimide is intact, and the barrier layers are effective. Compared to the control data, no significant increase in 1/f noise can be observed. The Johnson noise of a 138 kOhm thermistor over this bandwidth – the minimum value theoretically possible for a resistive component - is about 100 nV, and total 1/f noise is about 10 dB above the Johnson level.

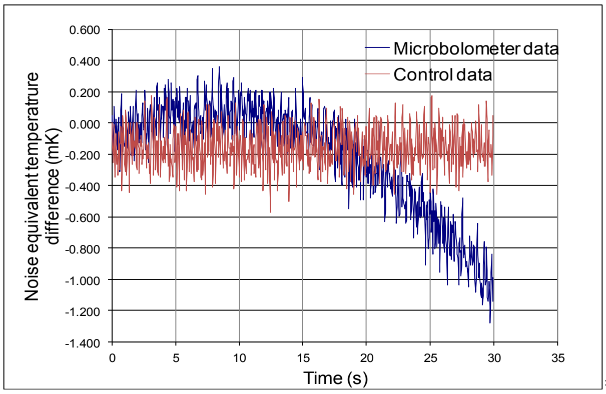


Figure 6: Microbolometer output signal (blue trace) versus control data (bridge of 4 metal film reference resistors).The blue trace responds to ambient temperature variations, whereas the red trace does not. Noise magnitude is similar, implying the thermistor noise is comparable to that of the metal-film resistors used.

A thickness of 12.5um of polyimide is thermally equivalent to a layer of about 1 to 2um of air (as the thermal conductivity of polyimide is roughly a factor of 10 higher, and the heat capacities are about the same).

We conclude these devices perform comparably to surface micromachined membrane-type devices with air gaps, but are less expensive to fabricate and more robust. Ongoing and future work focuses on characterization of the infrared absorption layer and full characterization of the microbolometers.

ACKNOWLEDGEMENTS

The authors thank John Lekki, Larry Liou, Viet Nguyen and team from NASA for the fruitful discussions. Lai Wong is acknowledged for her processing assistance and expertise.

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