UNCOOLED ALL-PARYLENE BOLOMETER

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ABSTRACT

This paper presents an uncooled, room-temeprature, all-parylene bolometer. The device is made of two layers of pyrolyzed (or "carbonized") parylene and a metal layer for interconnections. We demonstrated that high responsivity can be achieved by tailoring the electrical conductivity and the temperature coefficient of resistance (TCR) using different pyrolysis conditions for each parylene layer.

1. INTRODUCTION

Figure (1) shows a typical resistive uncooled bolometer: a free-standing temperature-sensitive element is linked to a substrate by low thermal conductance legs. Eq (1) shows the expression of the d.c. responsivity (in Volts per incident Watt) for such a device.

$$\Re(V.W^{-1}) = \frac{\Delta V}{P} = \frac{\alpha R I_{bias} \eta}{G}, \qquad (1)$$

where α is the TCR of the sensing element. R is the bolometer resistance, G is the pixel-to-substrate thermal conductance and η is the bolometer absorptance. The thermal time constant is given by:

$$\tau(s) = \frac{C}{G}, \qquad (2)$$

where C is the thermal capacitance. The key parameters to obtain good responsivity are: high pixel-TCR and low pixel-to-substrate thermal conductance. However, as we try to decrease the thermal conductance, we must be able to decrease the thermal conductance. Most uncooled bolometers use vanadium oxide [1] or amorphous silicon [2] as temperature-sensitive material, reaching a TCR of about 1.5% to 3%. Another possible material is YBaCuO [3].The suspension legs are usually made of silicon nitride or polysilicon. In the case of silicon nitride legs, it is necessary to have another layer for electrical conduction. Here, we propose a bolometer using pyrolyzed parylene both for the temperature-sensing element and for the suspension legs.

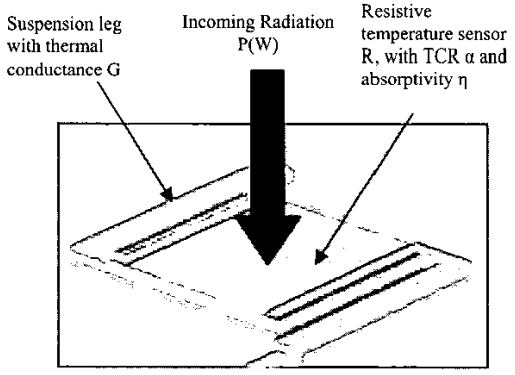

Figure 1: Standard Resistive Bolometer Structure

2. THERMAL PROPERTIES OF PYROLYZED-PARYLENE

Pyrolyzed parylene as a MEMS "sacrificial" material was first reported by Hui et al in 1998 [4], in which carbonized parylene is subsequently burned away in O_2 environment at high temperature. Other than that, It is also known that pyrolysis of polymers can lead to electrically conductive or partial conductive films [5]. Interestingly, our recent work showed that the electrical conductivity of pyrolyzed parylene can be adjusted over a very wide range (from insulating down to $\approx 10^{-2}\Omega\cdot$cm) depending on the pyrolysis conditions [6]. We studied the temperature dependence of the resistance of pyrolyzed parylene films. Figure (2) shows the temperature dependence of the resistance of a sample having a resistivity of $1.9*10^{3}\Omega$.cm at room temperature. As can be seen on this figure, the conductivity follows an Arrehnius dependence:

$$\sigma \propto \sigma_0 * e^{-E_a/kT}, \qquad (2)$$

where E_a is the activation energy.

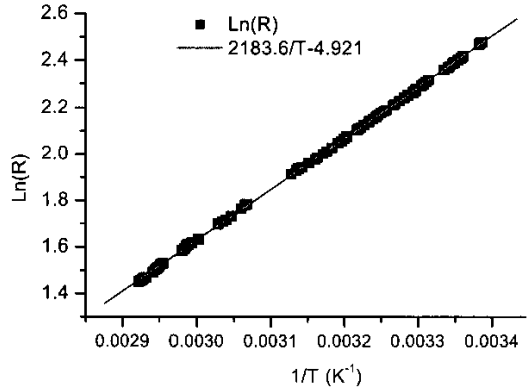

Figure 2: Resistance Temperature Dependence for Pyrolyzed Parylene

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For a resistivity having an Arrehnius dependence, the TCR is given by,

$$\alpha = -\frac{E_a}{kT^2}. \quad (3)$$

Like other materials often used in uncooled infrared sensors (vanadium oxide and amorphous silicon), the TCR of pyrolyzed parylene increases with resistivity. Figure (4) shows the TCR of various films having different resistivities (obtained by pyrolysis at different temperatures). The TCR of pyrolyzed-parylene does show a logarithmic dependence on the resistivity. The measured TCR was -4%/K for films having ~10^8Ω.cm resistivity down to -0.3%/K for films having ~10^{-2}Ω.cm resistivity. The corresponding activation energies are 0.023eV and 0.31eV respectively. Because higher bolometer resistance leads to higher thermal noise, there is a trade-off between high responsivity (given by high TCR) and signal-to-noise ratio (given by low resistance).

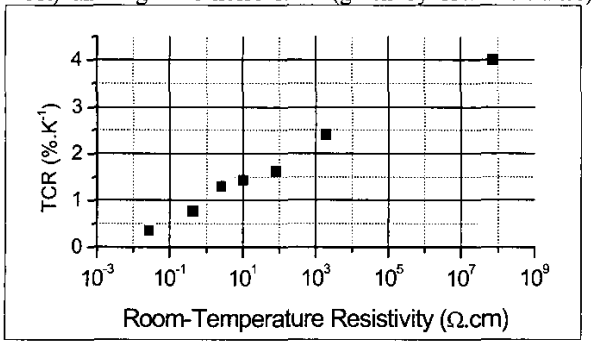


Figure 3: TCR vs. resistivity for various pyrolyzed-parylene films

While measuring the temperature dependence of the films in air, it was found that the resistivity of pyrolyzed parylene is sensitive to moisture. Therefore, the TCR measurements were performed in a vacuum chamber. Figure (4) shows the resistance drop of a pyrolyzed-parylene film when exposed to air after being stabilized in vacuum. This resistance change is reversible. However, this sensitivity to moisture is not a problem for our application since uncooled bolometers operate in vacuum (for thermal insulation purposes).

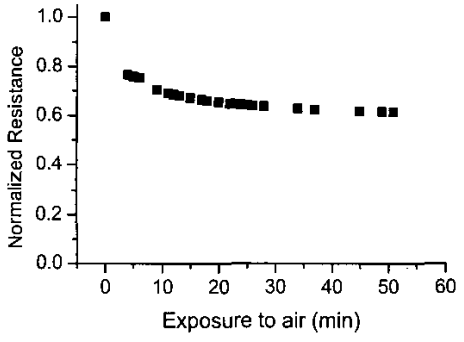


Figure 4: Resistance drop when exposed to air after vacuum

2. DESIGN

Since our ultimate goal is the build an uncooled IR focal-plane array, the bolometer design is similar to that shown on figure (1). The pixel size was chosen to be 50x50μm^2, a standard size allowing acceptable resolution with a chip-sized array. For this geometry, the total pixel resistance is given by:

$$R = 2R_{leg} + R_{pixel}, \quad (4)$$

assuming we can neglect contact resistances. Upon incoming radiation, most of the temperature increase occurs on the pixel. Therefore, to maximize the relative change in total resistance, the resistance of the pixel must be dominant over the resistance of the suspension legs. However, with such a layout, it is obvious that the number of electrical "squares" of the suspension legs is greater than that of the pixel (=1). For that reason, the sheet resistance of the suspensions legs must be much smaller than the sheet resistance of the pixel. The process-tunablity of the properties of pyrolyzed-parylene allows us to fabricate a bolometer meeting this requirement with a simple two-layers process. To allow comparison with VOx-based bolometers the target TCR was set around -2%, which according to figure (3) would be obtained for a resistivity in the order of 10^2 Ω·cm. The width of the suspensions legs was designed to be 5μm and their lengths varied from 50μm to 170μm, corresponding to a number of resistor squares varying from 10 to 34. Therefore, for the total bolometer resistance to be dominated by the pixel resistance, the resistivity of the suspension legs should be on the order of 10^{-1} to 10^{-2} Ω·cm (if the thicknesses are comparable).

3. FABRICATION

Process Flow

Our device process, figure (5), begins with a 5000Å oxide growth and patterning. A 3μm-thick parylene-C layer is then deposited and pyrolyzed in a nitrogen atmosphere. The temperature is raised to 800°C at 10°C/min then cooled down to room temperature at 2°C/min. The resulting film is patterned to define the suspension legs. The pyrolyzed-parylene etching is done in a PEII plasma etcher with 400W, 200mT of O2 using a photoresist mask. The etching rate of pyrolyzed-parylene was found to be comparable to that of parylene (~1800Å/min) for these same settings. A second layer of parylene (0.8μm) is deposited, and then pyrolyzed at 660°C (with the same ramping parameters as previously). For better repeatability, the samples are being kept at the pyrolysis temperature for 2 hours. The second layer of pyrolyzed parylene is patterned define the pixel area. Next, a Ti/Au interconnection layer (60Å/2000Å) is evaporated and patterned. Finally, the bolometers are released by XeF_2 gas-phase etching. Figure (6) shows a fabricated free-standing device.

Processing Issues

Typically, parylene depositions involve a prior coating of A174 for adhesion promotion [7]. However, it was found that

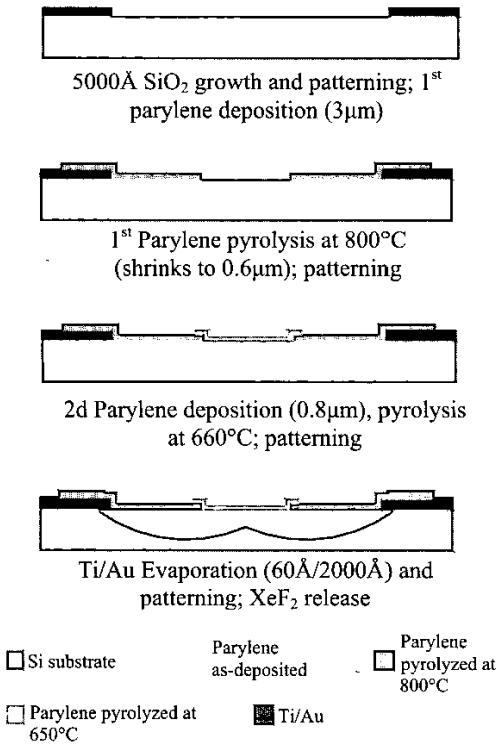


Figure 5: Process flow

this procedure leads to poor adhesion of the films after pyrolysis. On the other hand, the adhesion of pyrolyzed parylene on SiO_2/Si wafers that have not been coated with A174 was excellent. This is also part of the reasons why we chose to pattern the parylene after pyrolysis rather than the opposite. It was also observed that pyrolysis of pattern parylene leads to undesirable border effects, probably due to the pyrolysis-induced stress. Finally, due to the isotropic etching, patterning the parylene after it has been shrunk (4 to 5 times) by pyrolysis minimizes undercut.

4. CHARACTERIZATION

Sheet resistance and contact resistance were measured by Greek-cross structures. The contact between the pyrolyzed parylene layers and Ti/Au was found to be ohmic with a specific contact resistance of $3.5x10^{-3}$ $\Omega\cdot cm^2$ for first layer and 3.5 $\Omega\cdot cm^2$ for the second layer. The contact between the first and the second layer of pyrolyzed parylene was also ohmic with a specific contact resistance of 1.57 $\Omega\cdot cm^2$ The TCR of the second parylene layer around room temperature was measured to be -1.63%/K. Table (1) shows different characteristics of interest for the two pyrolyzed-parylene layers. The ratio between the sheet resistance of the first and the second layer is $8.7x10^3$. Therefore, for the chosen

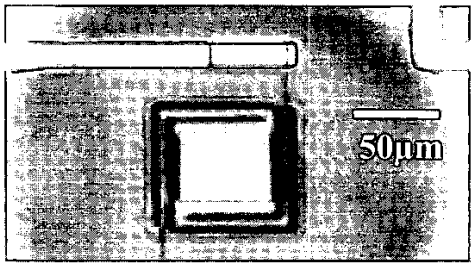


Figure 6: Fabricated bolometer

geometries, the total resistance of the bolometers is indeed dominated by the temperature-sensing element obtained from the second layer of pyrolyzed parylene.

Table 1: Parylene Layers Properties

	1st Layer	2d Layer
Pyrolysis Temp (°C)	**800**	**660**
Holding Time (min)	**0**	**120**
Thickness before pyrolysis	**3μm**	**0.8μm**
Thickness after pyrolysis	**0.6μm**	**0.2μm**
Sheet Resistance (Ω/□)	**456**	**$3.97x10^6$**
Resistivity (Ω·cm)	**$2.74x10^{-2}$**	**79.4**
Contact Resistance ($\Omega\cdot cm^2$)	**$3.5x10^{-3}$**	**3.5**

After wire-bonding and packaging, the bolometers were placed in a vacuum chamber (<1mT) and stabilized for several hours to eliminate any potential moisture-related drift. Current-Voltage characteristics of the bolometers were measured with an HP4145 working as a voltage source/current monitor. A hold time of 1 second was used at each bias to ensure thermal steady-state. Figure (7) shows the IV curve for a 50x50μm² bolometer with two 5μmx170μm suspensions beams. The upward curvature seen on this figure indicates self-heating (the TCR of pyrolyzed-parylene being negative). Unreleased bridges do not exhibit this self-heating.

Figure (8) shows the resistance and temperature rise as a function of input power. The temperature rise is calculated from the resistance change and TCR. The corresponding thermal conductance is $5.43x10^{-8}W\cdot K^{-1}$. Knowing the dimensions of the legs, we can estimate the thermal

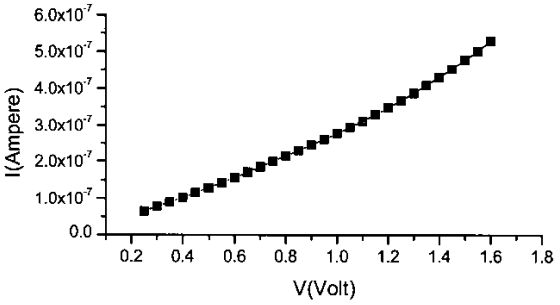
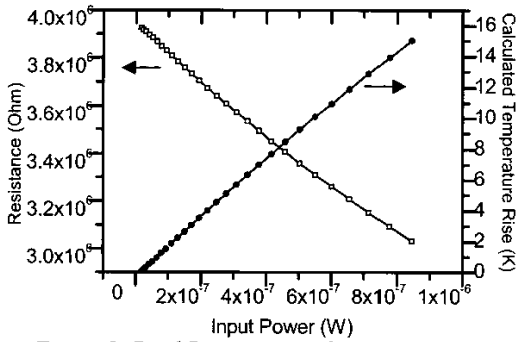


Figure 7: Bolometer IV characteristic

conductivity of the first layer of pyrolyzed parylene to be κ_{pp}=1.5 $W \cdot m^{-1} \cdot K^{-1}$. Similar calculations on other bolometers having different geometries (smaller suspensions legs) lead to lower thermal conductivities 1.1 $W \cdot m^{-1} \cdot K^{-1} < \kappa_{pp} < 1.5\ W \cdot m^{-1} \cdot K^{-1}$. This is comparable to values reported for PECVD silicon nitride [8-9] and lower than LPCVD nitride, with the major advantage of providing electrical conductivity. It is also one order of magnitude lower than polysilicon [10]. From the TCR and the thermal conductance, we can expect the responsivity to be $\Re = 3*10^5 * \eta$ (for a 1 Volt bias, and 5μmx170μm suspension legs), where η is the absorptance of the pixel. Although the sensitivity to incoming radiation was qualitatively observed, the absorptance of pyrolyzed parylene thin films for the wavelengths of interest (e.g. 8μm to 14μm for thermal imaging) still needs to be characterized.



.Figure 8: Pixel Resistance and temperature rise as a function of input power

However, because of the carbon-like properties of pyrolyzed parylene, we can expect the absorptance to be close to 1.

CONCLUSIONS

We have successfully fabricated uncooled infrared sensors with a simple two-layer pyrolyzed-parylene process. Electrothermal study shows that pyrolyzed-parylene is a promising candidate to replace silicon nitride and polysilicon for the thermal insulation, while it can also be used to achieve high-TCR thin films for the pixel. IR optical characterization as well as dynamic behavior is currently underway. Future work also includes the development of a purely surface-micromachining process, and the fabrication of a bolometer array.

ACKNOWLEDGEMENTS

This work was supported by the NSF Center for Neuromorphic Engineering (CNSE) at Caltech. The authors would like to thank Trevor Roper, Tanya Owen and Ted Harder for their assistance.

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