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This is the submitted version of a paper published in *IEEE Sensors Journal*.

Citation for the original published paper (version of record):

Ashraf, S., Mattsson, C., Thungström, G. (2019)

Fabrication and characterization of a SU8-epoxy membrane based thermopile detector with an integrated multilayered absorber structure for the mid-IR region

IEEE Sensors Journal

<https://doi.org/10.1109/JSEN.2019.2896668>

Access to the published version may require subscription.

N.B. When citing this work, cite the original published paper.

Permanent link to this version:

<http://urn.kb.se/resolve?urn=urn:nbn:se:miun:diva-35525>

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Fabrication and characterization of a SU8-epoxy membrane based thermopile detector with an integrated multilayered absorber structure for the mid-IR region

Shakeel Ashraf, Claes G. Mattsson, Göran Thungström

Abstract — This paper reports on the fabrication and characterization of a thermopile detector with an integrated mid-infrared absorber structure. The fabricated absorber structure has shown an absorption of more than 95% in the wavelength range of 3.2 – 5.47 μm . The detector was fabricated with standard cleanroom process techniques and equipment. The serial resistance was measured at about 315 k Ω at room temperature. The photosensitivity of the detector was characterized for a single wavelength (4.26 μm) and a band of wavelength ranging from 2.5 – 5.5 μm through two different measurement setups. In the first measurement setup, the photosensitivity was estimated at 57.5 V $\cdot\text{mm}^2\cdot\text{W}^{-1}$ through a MEMS-based infrared radiation source and with an optical band-pass filter of wavelength 4.26 μm . The following characterization was performed to characterise the photosensitivity of the detector in a broader wavelength range. This measurement was taken using a monochromator setup utilizing a reference photodetector for calculations of the optical power of the infrared source. The photosensitivity and the specific detectivity (D^*) of the fabricated detector were measured to values of 30-92 V $\cdot\text{W}^{-1}$ and 8.0×10^7 - 2.4×10^8 cm $\cdot\text{Hz}^{1/2}\cdot\text{W}^{-1}$, respectively, in the wavelength range of 2.8 – 5 μm . The time constant was estimated to around 21 ms.

Keywords—Interferometric absorber; thermopile detector; photosensitivity; SU-8 epoxy ; Transfer matrix theory.

I. INTRODUCTIONS

THERMAL detectors play an important role in different types of gas detection systems/applications. Room temperature operation of thermal detectors, such as the micro-thermopiles and bolometers, gives thermal detectors a significant advantage over photon detectors. The cooling requirement of photon detectors makes them bulky and expensive and, therefore, many cost-sensitive applications utilize thermal detectors. The use of this type of detector can be found in various applications, and an overall review of infrared (IR) detectors is presented in [1].

The sensitivity/performance of thermal detectors could effectively be increased by selecting membrane materials with low thermal conductivity values and an efficient infrared (IR) absorbing material/structure. Materials such as SU-8 epoxy have a very low thermal conductivity value of 0.2 – 0.3 W/mK [2][3]. This should be compared to other commonly used membrane materials, such as silicon and silicon nitrate, with thermal conductivity values of 150 W/mK [4] and 2.3 – 30 W/mK [5] respectively. Additionally, these membrane materials require advanced and expensive equipment, i.e. low pressure chemical vapour deposition or plasma-enhanced chemical vapour deposition equipment. The chemical vapour deposition process involves handling hazardous gases, which should be handled with care. In relation to this, the SU-8 deposition process only includes standard photo-lithographic processing steps, such as spin-coating and UV lithography. Such equipment is commonly available in most of the process facilities for detector fabrication labs. Furthermore, SU-8 is chemically resistant to most solvents and acids, and it is thermally stable up to 300 °C. The fabrication of an Al/Bi-thermopile detector using SU-8 epoxy as a membrane material has been reported in [6].

Graphite-based black paint has absorption values from 80 to 93% for a wide spectral range of wavelength 2.5 – 20 μm . The deposition of this type of absorber has been performed either by spraying directly onto the detector surface as reported in [7] or by using a very small brush. The use of a black paint as an IR-absorber has been reported in [8]. The deposition of such a layer is difficult in cleanroom facilities. These deposition methods could result in contamination, which restricts their use in cleanroom facilities. The membranes of the thermopile detector are very thin and fragile, and a rough deposition method could damage them. In addition, a thick and an uneven distribution of the absorber layer over the hot junctions would eventually increase the thermal capacitance of the detector, which results in a longer thermal response time.

The revised manuscript was submitted on 04 of March 2018. This paper is an extension of the original paper presented at the IEEE Sensor Conference 2016, which was published in its proceedings. The link to the original paper is provided here:

<http://ieeexplore.ieee.org/document/7808481/>
DOI: 10.1109/ICSENS.2016.7808481

This work was carried out at the Research Centre STC (Sensible things that communicate) at Mid Sweden University. STC is sponsored by the Knowledge Foundation in Sweden.

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Fig. 1: A simple representation of a thermal detector of thermal capacitance C_{th} , connected with supporting material with a thermal link of thermal capacitance G_{th} .

Thin metal films of sheet resistance $188 \Omega/\square$ could absorb 50% of incident radiation, as reported in [9]. The combination of a thin metal film (semi-transparent layer) with a dielectric medium of thickness $\lambda/4$ and a perfect reflector is known as an interferometric ($\lambda/4$) absorber. In theory, this structure has an absorption of 100% at a specific wavelength reported in [10], [11]. The construction of a $\lambda/4$ IR absorber structure based on SU-8 epoxy (as a dielectric medium) and its integration into the thermopile detector has been reported in [12], where the absorber structure, which was designed for a wavelength of $4.26 \mu\text{m}$, covers 81% of the detector surface — the surface area of the detector was 4 mm^2 and the absorber had an area of 3.24 mm^2 . The FTIR measurement showed more than 97% absorption for the structure. Due to processing limitations and variations, the maximum absorption of the $\lambda/4$ structure could possibly shift in wavelength as reported in [13], which eventually reduced the detector performance. However, the $\lambda/4$ structure could be improved by adding additional layers of dielectric medium and semitransparent metal. A multilayered $\lambda/4$ absorber structure has been reported in [14], where the structure was simulated for range of wavelength $3\text{--}6 \mu\text{m}$, and the FTIR results have shown more than 95% absorption in the range of $3.2\text{--}5.47 \mu\text{m}$. Since the multilayered structure utilizes SU-8 epoxy as a dielectric medium, this allows for a direct integration of this structure into the membrane. The fabrication and the integration of the absorber structure into the membrane of the thermopile has been reported in [15], where the detector voltage response and photosensitivity for a wavelength of $4.26 \mu\text{m}$ was also presented. In this extended paper, the thermopile detector was characterized for photosensitivity $\text{V}\cdot\text{W}^{-1}$, and specific detectivity D^* for the wavelength range of $2.5\text{--}5.5 \mu\text{m}$. The details about the fabrication and characterization are given in the following sections of the article.

II. THERMAL DETECTORS

A simple representation of a thermal detector is shown in Fig. 1, where a detector of thermal capacitance (C_{th}) is connected to a heat sink via a thermal link of thermal conductance (G_{th}) at a normal temperature (T). When radiation is incident on the detector, the radiation-sensitive material absorbs the incident radiation, and this results in a change in

Fig. 2: A simple representation of a thermocouple detector fabricated on self-supporting membranes, one junction is connected to a heat sink and the other connected to an IR-absorber.

temperature (ΔT). This change in temperature can be found by solving the heat equation in (1)[16]

$$C_{th} \frac{dT}{dt} + G_{th} \times \Delta T = \varepsilon \times \phi \quad (1)$$

where, (ϕ) is the incident radiation flux and (ε) is the emissivity of the active area. If the incident radiation flux is assumed to be periodic, the change in temperature (ΔT) is given by (2)[17].

$$\Delta T = \frac{\varepsilon \phi}{(G_{th}^2 + \omega^2 C_{th}^2)^{1/2}} \quad (2)$$

where, (ω) is the angular frequency of the incident radiation flux. From (2), we can observe that the change in temperature (ΔT) could effectively be increased by reducing both the thermal capacitance (C_{th}) and thermal conductance (G_{th}) values. Whereas to achieve fast detector response given in (3) [17], the value of (C_{th}) should be low and the values of (G_{th}) should be high. So, there is a trade-off between sensitivity and thermal response.

$$\tau_{th} = C_{th} / G_{th} \quad (3)$$

There is one way to increase the overall thermal response and sensitivity: by obtaining thermal isolation between heat sink and radiation sensitive element. Thermal insulation can be obtained by fabricating a self-supporting membrane structure for the thermopile detector. In Fig. 2, a simple representation of a thermopile detector is shown. Here, a cold junction lies on the heat-sink, and the hot junction connected with the IR-absorber and thermocouple is supported by the membrane material. When the IR-absorber receives incident radiation, the voltage response generated across the thermopile detector is directly proportional to the temperature difference and the number of thermocouples; this is known as the Seebeck effect, and the mathematical form is given by (4)

$$\Delta V = S_{AB}(T) \times \Delta T \times N \quad (4)$$

where, $S_{AB} = |S_A - S_B|$, S_A and S_B are the Seebeck coefficients of the materials, $\Delta T = |T_2 - T_1|$, T_2 and T_1 are the temperature of the hot and cold junctions, and N is the number of thermocouples. The Seebeck coefficient for Al metal is equal to $+4 \mu\text{V} \cdot \text{K}^{-1}$ and for Bi it is equal to $-70 \mu\text{V} \cdot \text{K}^{-1}$.

III. MULTILAYERED STRUCTURE

A. Simulation of the absorber structure

Absorption in the structure was calculated by using (5), where, T_{op} = transmittance, A_{op} = absorption, R_{op} = reflectance, and reflectance and transmittance coefficients were calculated by using the transfer matrix theory of multilayer structures [12]. The transfer matrix for each layer in the structure is described by (6).

$$A_{op} = 1 - R_{op} - T_{op} \quad (5)$$

$$\begin{bmatrix} \cos(\varphi) & \frac{-i}{n_l} \sin(\varphi) \\ -in_l \sin(\varphi) & \cos(\varphi) \end{bmatrix} \quad (6)$$

In (6) $\varphi = 2\pi n_l / \lambda_0$ and n_l is the complex reflective indices of the layer, ' t ' is the thickness of the layer and ' λ_0 ' is the optical wavelength. The overall transfer matrix is obtained by multiplying the individual matrices together such as

$$M_1 \times M_2 \times M_3 \dots M_j = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \quad (7)$$

The reflectance R_{op} and transmittance T_{op} are calculated by (8), and (9)

$$T_{op} = \text{Re}(n_T) \times |t|^2 / n_0, \quad R_{op} = \text{Re}(n_T) \times |r|^2 / n_0 \quad (8),(9)$$

Where ' r ', and ' t ' are the reflectance and transmission coefficients given in (8), and (9).

$$r = \frac{A \times n_0 + B \times n_0 \times n_T - C - D \times n_T}{A \times n_0 + B \times n_0 \times n_T + C + D \times n_T} \quad (10)$$

$$t = \frac{2 \times n_T}{A \times n_0 + B \times n_0 \times n_T + C + D \times n_T} \quad (11)$$

Where n_0 and n_T are the refractive index values of the infinite media above and below the structure, if the air is on both sides, then n_0 and n_T will become '1'. The simulation of the structure presented has been performed in MATLAB by implementing the transfer matrix theory. In the simulation, the thickness of the layers is selected to obtain maximum absorption in the wavelength region of $3 \mu\text{m} - 6 \mu\text{m}$. In simulation, refractive index values of the metals were taken from [18]. The index values of SU-8 epoxy are only known for the UV-visible region. In our simulation, we have considered

Fig. 3: Black dotted line represents FTIR measurements, blue dash-dot line represents the simulation results without considering the absorption in SU8, and red dashed line represents the simulation results with considering absorption in SU8.

$n_0 = 1.571$, and $k = 0$. The simulation result for the multilayered structure is shown in Fig. 3 (Simulation-1).

B. Fabrication and FTIR results

A multilayered absorber structure was fabricated. This structure consists of a stack of five layers. The bottom layer is a mirror layer ($1000 \text{ \AA}$ aluminum); this is followed by the first dielectric medium layer of SU-8 epoxy ($2 \mu\text{m}$), then by a titanium metal layer ($200 \text{ \AA}$), a dielectric medium layer of SU-8 ($0.6 \mu\text{m}$), and finally by a second titanium metal layer ($75 \text{ \AA}$), and the cross-sectional view is shown in Fig. 4f. The Fourier transform infrared spectroscopy (FTIR) measurement is shown in Fig. 3 (FTIR measurement). The initial results showed a rather high mismatch between simulation and measurement. The mismatch was investigated, and it was found that SU-8 epoxy has 10–20% absorption in the IR region $3 - 6 \mu\text{m}$ reported in [14]. By introducing ' k ' the absorption values of SU-8 epoxy into the simulation and FTIR measurement showed better correspondence shown in Fig. 3 (Simulation-2). The multilayered absorber structure shows more than 95% absorption in the wavelength range $3.2 - 5.47 \mu\text{m}$ in FTIR measurements and $3.30 - 5.0 \mu\text{m}$ in simulations.

IV. DETECTOR FABRICATION

A. Detector fabrication

The detector was fabricated using standard processing techniques. The fabrication process includes oxidation of the silicon wafer and wet and plasma etching of the silicon dioxide and SU-8 epoxy material, respectively. The photolithography processes include etching, lift-off processes and thermal evaporation of different metals. The cross-sectional view of the fabricated thermopile detector is illustrated in Fig. 4, and the overall detector fabrication process is described below.

Silicon wafer of type ' n ', orientation $\langle 100 \rangle$, polished on both sides, was selected as the bulk material (substrate). A $5000 \text{ \AA}$ thick layer of oxide was formed by a thermal oxidation process, as shown in Fig. 4a. Following this, square openings were formed in the oxide layer on the back for the etching of the silicon. Then, thermocouples (Al/Bi) were formed on the front side of the substrate by using a photolithographic and lift-

Fig. 4: A step-by-step fabrication process of the integration (of an absorber structure) and fabrication of a thermopile detector

off process. A thin layer of titanium was deposited before each metal evaporation in order to promote adhesion between the substrate and thermocouples. For electrical connection, aluminum contact pads were formed in a later process step. Later in the process, a layer of SU-8 epoxy **was formed by spin coating process** so as to insulate the thermocouples from the multilayer structure. These steps can be seen in Fig. 4b, including openings for contact pads. Metals, such as aluminum, have poor adhesion on SU-8 epoxy, which results in device yield problems. Oxygen gas plasma treatment enhances adhesion of metal on polymers as reported in [19]. Thus, wafer was treated with an RF oxygen plasma to enhance the metal adhesion on SU-8 epoxy.

The fabrication process continued with the integration of the multilayer structure into the membrane of the thermopile detector. Initially, a mirror layer of aluminum with a thickness of $1000 \text{ \AA}$ was deposited. This was followed by **spin coating** of a $2 \mu\text{m}$ SU-8 epoxy and evaporation of a $200 \text{ \AA}$ titanium layer. The fourth layer of the structure was another layer of SU-8 epoxy with a thickness of $0.6 \mu\text{m}$; in the fifth and final stage, a $75 \text{ \AA}$ titanium layer acting as semitransparent mirror was deposited. The cross-sectional view of the integrated multilayer structure is illustrated in Fig. 4c and a magnified view of the integrated multilayer structure is shown in Fig. 4f. Following the integration process, Pro-TEK B3 reported in [20] was used as an etch protection on the front of the detector as shown in Fig. 4d. After the completion of the etching process the cross-sectional view of the Al/Bi- thermopile detector is shown in Fig. 4e. A top view photograph of the thermopile detector is shown

Fig. 5: Top view of the fabricated thermopile detector with integrated multilayered structure.

Fig. 6: A block diagram of the measurement setup used for the photosensitivity measurement of the thermopile detector.

in Fig. 5. Here, the green part on the detector is the absorber structure.

V. DETECTOR MEASUREMENT PREPARATION

A. Measurement Setup

A block diagram of the whole measurement setup is shown in Fig. 6. TRIAX 180 monochromator from Horiba Scientific [21] was used in this measurements. A grating for the mid-IR region $2 - 6 \mu\text{m}$ wavelength was installed in the monochromator. The grating has a groove density of 300 gr/mm , and the spectral efficiency curve of the grating is available at [22]. IR-18 from SciTec Instruments [23] was used as an IR power source that was positioned at the input of the monochromator. Plano convex lenses were used for the collimation of the input signal and for focusing of the output signal to the detector. An optical chopper was used to modulate the input signal. The infrared source, the convex lens, and the optical chopper were all well aligned and positioned with the monochromator in order to maximize the input signal at the monochromator input. For focusing the output signal, a convex lens was positioned at the output of the monochromator. The detector was aligned behind the lens using an xyz-translation stage. The whole setup was enclosed in a measurement chamber, which was flushed with nitrogen (N_2) gas in order to minimize radiation absorption from carbon dioxide (CO_2) in the measurement chamber. The frequency of the optical chopper, and the output signal from the detector, were both fed to a lock-in amplifier. The monochromator and the lock-in amplifier were connected with a computer for storage of the captured data.

B. Calibration of the Monochromator

The monochromator setup was initially calibrated in order to characterize the wavelength dependent photosensitivity of the thermopile detector. In the mid-infrared wavelength band, carbon dioxide has a well-defined absorption peak at $4.26 \mu\text{m}$ [24], which could be used as a reference point for the calibration of the monochromator setup. The measurement setup shown in Fig. 6 was used for the calibration process. To achieve a high resolution in the calibration, the width of both entrance and exit slits was reduced to 0.5 mm . The output signal passing

Fig. 7: An IR scan from 4–4.5μm in order to calibrate the monochromator through the carbon dioxide absorption peak.

through the exit slit of the monochromator was focused onto a photodetector using a plano convex lens. The optical chopper frequency was set to 3 Hz, and a scan from 4–4.5 μm wavelength with a resolution of 1 nm was conducted. The output signal from the lock-in amplifier was logged and plotted in Fig. 7. In this figure, we can clearly observe the CO₂ absorption peak is at 4.222 μm, which is shifted about 38 nm towards the shorter wavelength. The shift in wavelength was noted down and entered into the software to correct the measurements according to calibration value.

VI. MEASUREMENT, RESULTS AND DISCUSSION

In this section, the measurement results of the thermopile detector through two different measuring setups will be discussed. First, the thermopile detector was characterization for a voltage response and a photosensitivity using a MEMS based IR source with and without optical filter of 4.26 μm wavelength will be present. In the second measurement setup, the photosensitivity and specific detectivity results of the thermopile detector for the wavelength range 2.5–5.5 μm through a monochromator setup will be discussed and presented.

A. Voltage response measurement for the fabricated detector

By using bulk values of the materials, the serial resistance of the thermopile detector was estimated to 75kΩ. However, the serial resistance of the thermopile detector was measured by connecting the device to multi-meter and found to be about 315 kΩ. The resistance of thin films is higher compared to resistance to bulk values reported in [25]. The serial resistance of thermopile detector is 4.2 times higher than the estimated values. Moreover, the contact resistances of the thermocouple junctions also contribute to higher serial resistance compared to theoretical values.

A MEMS based IR-emitter, packaged in a TO39 metal header, without glass window, manufactured by Axetris, was used to measure the voltage responses of both the thermopile detector and a reference detector (HMS J21 thermopile from Heimann Sensor GmbH [26]). The net radiation power of the IR emitter is 55.9 mW/m²K⁴ at 456 C and gives an IR spectrum range of 2–14 μm. The IR-emitter is connected to the

Fig. 8: Both blue lines (solid line and dashed) represents the measurement results for the thermopile and reference detector without optical filter, and both red lines (dotted and dashed) represents the measurement data with an optical filter of wavelength 4.26 μm.

controller (IRS LabKit G1) which is controlled by a computer software.

For our measurements, the IR-emitter was set at a 50% duty cycle and 2 Hz modulation frequency. The measurements were performed by placing both detectors, each at a time, 0.5mm away from the IR emitter. The reference detector has a wide absorption band compared to our thermopile detector, which is designed for maximum absorption in a narrow band 3.13–5.5μm. This results in a difference in the optical power absorbed in the detector. The voltage responses of both detectors are Fig. 8 (left y-axis). The voltage responses of the thermopile detector and reference detector were measured to 72.4mV and 68.7mV, respectively. The thermopile detector has a slightly higher voltage response than the reference detector even though it has a narrow band absorber. The radiation flux of the emitter was calculated at 1.76 mWmm⁻², by using the specific voltage response value, 39 Vmm²W⁻¹, of the reference detector. For the fabricated thermopile detector, the electric voltage responsivity value was calculated to 41.13 Vmm²W⁻¹.

Using a pulsed laser diode source of wavelength 1.55 μm, the time constant of the thermopile detector as well as the reference detector was measured to 21 ms and 11 ms, respectively. The time constant of the reference detector corresponds well to the specified value given in the datasheet. A previously fabricated SU-8 thermopile detector with a black paint absorber, reported in [27], was measured to have a time constant of 70 ms using the same laser diode IR source.

B. Voltage response measurement with optical filter

Carbon dioxide has an absorption peak in the IR spectrum at 4.26 μm. By introducing an optical band-pass filter at this wavelength, the thermopile detector can be used for the detection of CO₂. This system is known as a NDIR system and is commonly used for gas detection.

The second measurement was performed by placing an optical filter with a wavelength of 4.26μm in front of the IR emitter. The voltage responses of the thermopile as well as the reference detector were measured to 156.2 mV and 106 mV, respectively. Voltage response values for both detectors were amplified 1000 times by using a low noise amplifier, the

(a)

(b)

Fig. 9: (a) A solid line plotted on left y-axis shows photosensitivity results while a dashed dotted line on right y-axis shows IR source optical power in watts for the reference detector, (b) A dashed dotted line on the right y-axis represents voltage response (V) for the thermopile detector, and a solid line plotted on left y-axis shows photosensitivity results of the thermopile detector.

measurement results are Fig. 8 (right y-axis). For the thermopile detector, the photosensitivity value was estimated to $57.5 \text{ V} \cdot \text{mm}^2 \text{W}^{-1}$, which is more than 32% higher than the reference detector. The increased photosensitivity and response speed is a result of high absorption and a reduction in thermal capacitance and conductance due to the integration of an absorber structure.

C. Characterization of optical output power.

An InAsSb photo detector from Hamamatsu was used as a reference detector. The reference detector was used to calculate the output optical power of the IR source used in the measurements. The measurement chamber was flushed with N_2 about an hour before the measurement was started, and it continued during the measurement to remove contaminations from the surrounding atmosphere in the chamber. The infrared source was supplied with electrical power of 18W to get maximum optical power, and the frequency of the optical chopper was set to 3 Hz, and fed back to the lock-in amplifier. The reference detector was well aligned and positioned to get maximum output signal from the exit slit of the monochromator. The entrance and exit slit opening of the monochromator was set at 2 mm. The measurement was performed for the wavelength range of $2.5 - 5.5 \text{ } \mu\text{m}$ with a resolution of 10 nm. The photosensitivity value of the reference detector was calculated by using the measured output current signal and the specific detectivity (D^*) values of the reference detector. Fig. 9a (left y-axis) shows the calculated photosensitivity $\text{mA} \cdot \text{W}^{-1}$ of the reference detector. The optical output power of the emitter was calculated by dividing the output current signal by the photosensitivity value of the reference detector, and the results are plotted in Fig. 9a (right y-axis).

D. Characterization of the detector spectral response

The fabricated thermopile detector was mounted on a translation stage, positioned and aligned at the focal point of the plano convex lens to achieve maximum output signal. The measurement setup was flushed with N_2 about an hour before the measurement started, and it continued during the

measurement to minimize the contaminating effects of the surrounding atmosphere on the results. The entrance and exit slit of the monochromator was set to 2 mm, and the optical chopper frequency was to 3 Hz.

The measurement was taken for a wavelength range of $2.5 - 5.5 \text{ } \mu\text{m}$ with the resolution of 10 nm. The voltage response of the thermopile detector is plotted in Fig. 9b (right y-axis), and can be seen to follow the blackbody radiation curve. As presented in Chapter VI section C, the power for the infrared emitter was determined as a function of the wavelength. Hence, the photosensitivity, V/W , of the thermopile in this wavelength range could also be determined and plotted in Fig. 9b (left y-axis). Here, the maximum photosensitivity value of about 92 V/W was found at a wavelength of $2.84 \text{ } \mu\text{m}$, and decreases gradually with increasing wavelength. At $5 \text{ } \mu\text{m}$, the photosensitivity was found to be about 30 V/W . The detector has 65 V/W and reference detector has 4.2 mA/W photosensitivity at $4.26 \text{ } \mu\text{m}$ wavelength, respectively. The photosensitivity of the reference detector is in mA/W as it is a photo diode detector.

Fig. 10: A solid line plot on the left y-axis shows calculated specific detectivity, and the dashed dotted line plot on the right y-axis represents the noise equivalent power of the thermopile detector.

The multilayered absorber structure, presented in Chapter III section A, was fabricated and characterized independently. During the integration into the membrane of the thermopile, the layer thickness of the SU-8 epoxy could have some thickness variation due to processing limits. This variation of the SU-8 epoxy could shift the absorber band in wavelength, and thus the multilayered absorption band could differ slightly from the results presented for the separate absorber structure.

The whole purpose of the multilayered structure was to achieve maximum absorption in the mid-infrared region for the use in detection of gases such as CO₂ and methane (CH₄). For example, CO₂ and CH₄ have strong absorption peaks at 4.26 μm , and at 3.3 μm , respectively. For these wavelengths, the detector has shown a photosensitivity values of about 65 V·W⁻¹ and 80 V·W⁻¹, as shown in Fig. 9b (left y-axis).

The characterization verify that the fabricated thermopile with an integrated multilayered absorber has high photosensitivity in a broad wavelength range. The specific detectivity (D^*) cm·Hz^{1/2}·W⁻¹ and noise equivalent power (NEP) nV·Hz^{-1/2} was calculated from the measurement data, and plotted in Fig. 10. Here, the thermopile detector shows a specific detectivity value that varies from 8.0×10^7 to 2.4×10^8 cm·Hz^{1/2}·W⁻¹ for a wavelength range of 2.84–5 μm . The detector has dectivity of 1.9×10^8 and referecne detector has 9×10^8 value, which is compartivly lower then reference detector because reference detecotor is silicon based photo detector.

With the current design parameters of the multilayered absorber, the thermopile could be used in detection systems for a mid infrared region of about 3–5 μm . However, by tuning the absorber structure parameter, it could be used for other adjacent wavelength regions.

I. SUMMARY AND CONCLUSION

In this paper, we have presented an integration process of a mid-infrared absorber (multilayered $\lambda/4$) structure into the SU-8 membrane of a thermopile detector. Measurement results of the thermopile detector have been presented. The absorber structure shows an absorption of more than 95% in the range of 3.13–5.47 μm . Using standard fabrication techniques, a complete fabrication process has been demonstrated. The serial resistance of the detector was measured to about 315 k Ω . A MEMS based infrared emitter was used for initial e characterization of voltage response. These measurements were taken in two stages with and without an optical filter: in the first stage, the voltage response of the thermopile detector was measured using the entire radiation band of the emitter. The voltage responses were measured to 72.4 mV and 68.7mV for the thermopile and reference detector, respectively. The optical radiation power of the emitter was estimated to 1.76 mWmm⁻² by using the specified voltage response of the reference detector. For the presented thermopile detector, the photosensitivity was calculated to 41.13 Vmm²W⁻¹. The time-constant value of the thermopile detector was estimated to around 21 ms. This is a noticeable reduction compared to values presented previously, caused by integrating the absorber structure and, therefore, reducing the thermal capacitance. In the second stage, an optical bandpass filter with a narrow passband at a wavelength of 4.26 μm was placed between

emitter and detector. With this setup, the voltage response was measured to 156.2mV and 106mV for the presented detector and the reference detector, respectively. The photosensitivity of the detector presented was increased to 57.5 Vmm²W⁻¹. This increase in photosensitivity was caused by an efficient absorber. The integration of the absorber in a membrane material consisting of a material with low thermal conductivity contributes the increasing the photosensitivity.

The spectral response of the detector was characterized for the wavelength range of 2.5 – 5.5 μm . The characterization was performed by using a monochromator setup. The output signal from the monochromator was modulated using an optical chopper and focused on the detector. For the noise reduction and amplification, the chopper frequency and the output signal from the detector were fed to a lock-in amplifier. The optical input power was characterized by using a referece photodetector with the specified photosensitivity. The detector has shown a maximum photosensitivity value of 92 V/W at a wavelength of 2.84 μm . This value gradually decreased with an increase in wavelength to 30 V/W at about 5 μm . For the region 4–4.5 μm , which is interesting for detection of CO₂, and the region 3.1–3.5 μm that is interesting for the detection of CH₄, the detector has shown a photosensitivity value higher than 65 V/W. The thermopile detector has a photosensitivity ranging from 30 to 92 V·W⁻¹ and a specific detectivity value from 8.0×10^7 to 2.4×10^8 for the wavelength range of 2.84–5 μm . The detector presented was mainly designed for the detection of gases in the mid-infrared region, such as CO₂ and CH₄. However, for the detection of other gases, tuning the absorption parameters could shift the absorption band up or down in the wavelength spectrum.

ACKNOWLEDGMENT

The research has been carried out in the STC (Sensible Things that Communicate) research centre at Mid Sweden University. We would like to acknowledge SensAir AB

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