CO_2 detection using Al/Si Schottky diode by IR spectroscopic technique

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***Abstract*—In this study, utility of aluminum-silicon (Al/Si) Schottky diode is demonstrated as an optical detector of carbon dioxide (CO_2) in NIR (1.57 and 1.60 µm) region. For this purpose, a self-fabricated Al/Si Schottky diode (barrier height 0.71 eV) and a broad band infrared irradiation source were used. An acrylic sheet were used to filter higher wavelength irradiation. Schottky diode was fabricated by depositing aluminum on patterned n-silicon (resistivity 0.2-0.4 Ω-cm) by thermal evaporation technique. Presence of CO_2 between the detector and the irradiation source showed decrease in reverse bias current up to 15 %. It is proposed that the demonstrated technique can be successfully employed in real time applications involving CO_2 detection.**

***Keywords*— CO_2 detection; spectroscopic technique; Schottky diode; infrared gas detection**

I. Introduction

Technological boost in industrialization and mechanization, resulted in emission of greenhouse gases such as CO_2. This in turn resulted in health hazards and major ecological imbalances. More over CO_2 in conjunction with remnants of poorly combusted fossil fuels emitting from petroleum industries and mine environments create serious health hazards. Hence, monitoring the concentrations of greenhouse gases in atmosphere is a global concern. The infrared spectroscopic techniques are the most important in detection of gas where gas is being detected through the characteristic absorption due to molecular vibrations modes or their combinations. These molecular vibrations modes are found to be the range of mid infrared regions and the overtones are lies in the higher frequency regions [1]. Important molecule like CO, CH_4 etc. have characteristic absorption lines in the range of 0.75 to 2 µm region [2]. However, these overtone or combination features have weak signal strength when compared to the main vibration modes. On the other hand this spectral range coincide with optical transmission window of telecommunication [3]. In more recent days, spectroscopic techniques are gaining importance to detect simultaneously two or more gases using absorption characteristics in NIR regions. The absorption feature of the gas in investigated in this work, CO_2, has a spectral absorption feature centered around 1.6 µm [2].

In this study, we report the fabrication of Schottky diode as an optical gas detector operating at 1.6 µm absorption line corresponding to CO_2. A broad band IR source and Schottky optical detector arrangement were used to detect CO_2. Conventionally, p-i-n diodes and pyroelectric detectors are used for this purpose. But, to the proposed technique is advantageous to above mentioned optical detector by virtue of its compatibility with CMOS technology and low manufacturing cost. To detect 1.6 µm (0.775 eV) IR, a Schottky diode of higher cut-off wavelength is required. Hence Aluminum Silicon Schottky (Schottky barrier height 0.69±0.1 eV, cutoff wavelength 1.79 µm) contact is a best choice to reduce the device cost as well as increase the sensitivity.

II. Experiment

A. Fabrication of Schottky device

Boron doped n-type silicon (100) wafer of resistivity 0.2-0.4 Ω-cm was used to fabricate Schottky diode. At first RCA cleaning was performed and then patterned by lithographic technique to define front side electrode of dimension 5 micron and spacing of 10 micron. HF dip was done for 15 sec on patterned wafer to remove native oxide formed during the process. Wafer was then immediately loaded to the thermal evaporator to deposit Aluminum (Al). 30 nm Al was deposited by thermal evaporation technique. Deposition was performed in base vacuum 5e-6 mbar and deposition was done in the pressure of 5e-3 mbar. Liftoff was done by using acetone. Then wafer was loaded for rapid thermal annealing at 300 ^{0}C for 30 sec. BHF (5:1) was used to remove backside oxide. Then wafer was loaded in thermal evaporator to deposit aluminum in backside of wafer for back contact. The fabrication process steps is shown in fig 1.

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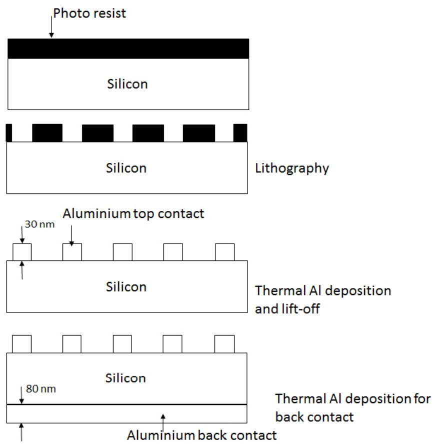

Figure 1: Al/Si Schottky diode fabrication process flow

B. Detection of gas

Device is then mounted on Teflon device holder and copper wire was used as a probe. Gas chamber was constructed by using acrylic sheet of volume 1000 cm^3. For irradiation, a broad band source IR lamp (Lowel Pro-Light) was used. Carbon dioxide (90% pure) cylinder was used as a CO_2 source. The block diagram of experimental arrangement is shown in fig 2. Current–Voltage (I–V) measurement was done by Keithley 2400 source meter with software interface in presence of CO_2 (I_{Gon}) and in absence of CO_2 (I_{Goff}).

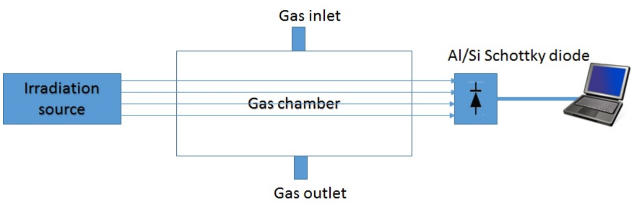

Figure 2: Block diagram of experimental setup

III. RESULTS AND DISCUSSIONS

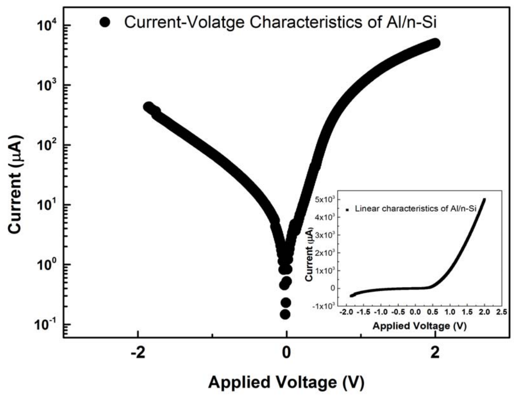

Figure 3: I-V Characteristics of Al/n-Si Schottky diode inset showing the linear characteristics

Current–Voltage characteristics of the Schottky diode is shown in fig 3. The measurement was done in room temperature (300 K). According to thermionic emission theory [4]:

$$I=AA^{*}T^{2}\exp(q\Phi_B/kT)[\exp(qV/\eta kT)-1] \qquad (1)$$

$$J=A^{*}T^{2}\exp(q\Phi_B/kT)[\exp(qV/\eta kT)-1] \qquad (2)$$

where J, A, A^*, η, k, T and q are the current density, effective area of the diode contact (0.02 cm^2), effective Richardson constant for n-Si (120 A/cm^2-K^2 [5]), ideality factor, Boltzmann constant, temperature and electron charge respectively.

Equation (2) can be re written as

$$J=J_o[\exp(qV/\eta kT)-1] \qquad (3)$$

Where

$$J_o=A^{*}T^{2}\exp(q\Phi_B/kT) \qquad (4)$$

Barrier height was calculated by using (4) and it was found to be 0.71 eV, which is comparable as reported in [5,6].

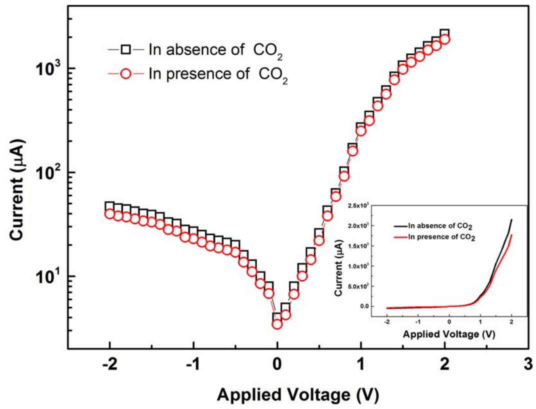

Figure 4: I-V characteristics of Schottky diode in presence and absence of CO_2 the linear plot is shown in inset

Current–Voltage characteristics in presence and absence CO_2 is shown in fig 4. Current was found to decrease in presence of CO_2. This change of current is attributed to the partial absorption of CO_2, which effectively reduces the light intensity on the detector, and hence, the photo generated current becomes less; such behavior can be explained by Beer Lambert absorption law:

$$I_t=I_0\exp(-\alpha ln) \qquad (5)$$

where I_0 is the intensity of light in air medium, n is the molar fraction of CO_2, α is absorption coefficient of CO_2 and I_t in the transmitted intensity and l is the path length traversed by the light. Hence in presence of CO_2 there will be drop of light intensity. And as the photocurrent is linearly depend on the light intensity falling on the photo diode [7] hence there will be drop of photo current in presence of CO_2.

The percentage change of current due to presence of CO_2 is shown in fig 5. Where $\Delta I=I_{Goff}-I_{Gon}$. It can be observed that the response (percentage change of current) is slightly (~0.5%)

increasing with the applied reverse bias voltage. The average value of the response is 15% to the absence of CO_2. The highest value (15.5%) was observed at 2 V reverse bias.

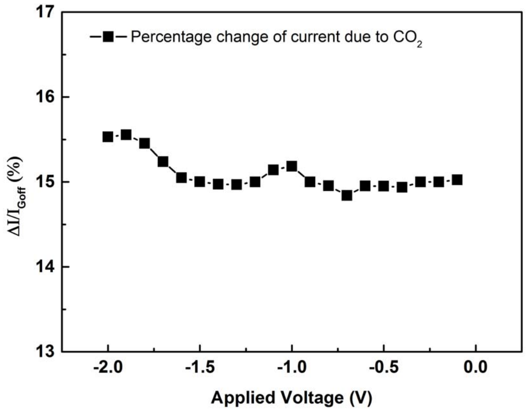

Figure 5: Percentage change of current in presence of CO_2 to the absence of CO_2

IV. CONCLUSSION

This work reported the development of CO_2 detection sensor by spectroscopic technique using Schottky diode as an optical detector and a broadband IR irradiation source. Al/n-Si (100) Schottky diode was fabricated with a barrier height of 0.71eV, characterized and tested for its performance. The change of current value was found to be 15±0.5%. From the results presented above, it is evident that this device can be successfully employed in detection of CO_2 along with an IR source.

Acknowledgment

The authors would like to thank to Mr. Rishikesh Bharti, Kalimuthu Rajendran; Earth Science, Indian Institute of Technology Bombay and Mr. Soumitra Keshary Nayak; Centre for Nano Technology and Science, Indian Institute of Technology Bombay for their sincere help during the gas testing. The authors would like to thanks IITBNF for providing us the facilities to fabricate device.

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