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Effect of Operating Temperature on Performance of Obliquely Deposited Bi, Sb and Bi-Sb Semimetal Thin Film Laser Detectors

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Abstract: Obliquely deposited (70^o) Bi, Sb, and Bi-Sb alloy thin films have been prepared by thermal resistive technique. Structural properties of these films were studied using XRD. Their resistance and voltage responsivity for Nd:YAG and CO_2 laser pulses have been recorded as function of operating temperature between 10 ^{o}C and 120 ^{o}C. It was found that the maximum responsivity for these detectors can be obtained at 75 ^{o}C. On the other hand, the dependence of responsivity on the width of detectors was investigated.

Introduction

The study of Bi and Sb is particularly interesting as potential thermoelectric material because of their semi-metallic behavior, the low Fermi energy, small effect mass of their conduction electrons, high electron mobility, highly an isotropic Fermi surface [1-5]. Due to its small thermal capacity and fast response time they finding increasing applications in pulsed laser detectors PLD [6,7]. The electrical resistivity and thermoelectric power studies that have been made on Sb and Bi films revealed that a large inconsistencies. This could be attributed to the deposition condition [8]. No data are available on the effect of temperature on the electrical resistivity, thermoelectric power, and laser detection performance of obliquely deposited Bi, Sb and Bi-Sb thin films.

This work aims firstly to study the dependence of resistivity and thermoelectric power on the operating temperature of Sb and Bi films deposited at slant angle 70º, and secondly, to investigate their ability to detect laser pulse at various temperatures.

Experimental

Thin films of high purity Bi, Sb, and Bi-Sb alloy were deposited through a thin metal masks at slant angle 70º (optimum angle) [9] with length of 47 mm and width of 1 and 2 mm by thermal resistive technique onto cleaned glass substrate. Fig (1) shows the configuration of thermal evaporation system, where θ is the angle of incidence which the Bi or Sb vapor stream makes with the normal to glass substrate. No substrate heating has been used prior deposition process. The vacuum pressure was down 10^{-5} Torr. The evaporation source was Mo boat and the deposition rate was 5 nm/s and the thickness of all films was 200 nm. Electrical contacts have been made on Sb, Bi and Bi-Sb alloy by deposition a thin layer of gold and then bonded to the gold wire by silver paste.

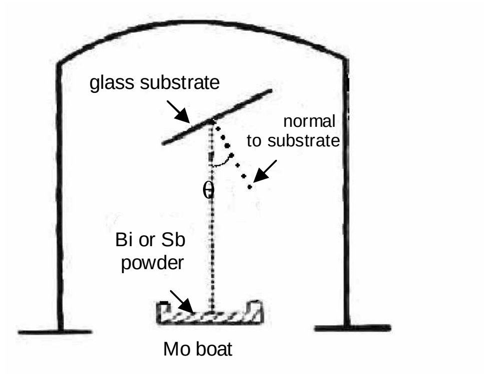


Fig. 1: A schematic diagram of oblique deposition technique.

The measurements of the film resistance R as function of temperature T (10-180º C) and film width were carried out in vacuum (10^{-3} Torr). Bi, Sb and Bi-Sb films have been used to detect Nd:YAG laser pulses under different operating temperatures. The pulsed laser used in this study is characterized by 1.064 μm wavelength, TEM_{00} mode and 200 μs pulse width. To reduce the electrical noise, the detectors were placed in a metal shielding box.

Results and Discussion

Fig. (2) shows the variation of R with T of Bi and Sb films. For Bi, it is obvious that R decreases with T up to 70 º C, thus exhibiting a negative temperature coefficient of resistivity and hence non-metallic behavior at low temperature (semiconducting properties). The decreasing in resistance with increasing temperature could be attributed to the decreasing of the whole mobility of resistance is lower. For Sb film no significant change in the resistance with temperature has been observed at low temperature region. For high temperature 150º C pronounced increment in resistance obtained for both Bi and Sb (metal characteristics).

The R-T plot for Bi-Sb alloy film is demonstrated in Fig. (2- c). At low temperature the resistance is decreased exponentially with temperature (impurity conductivity) and finally at highest temperature the resistance increased linearly with temperature (grain boundary barrier activation region). This behavior is in good agreement with that for normal incidence deposited Bi-Sb film obtained in Ref. [1]. Fig. (3) presents the relationship between Seebeck coefficient S and temperature for Sb, Bi and Bi-Sb films. It is clear from that figure the Seebeck coefficient linearly dependence on temperature. The value of S at 30 º C for normal incidence deposited Sb film is lower than that obtained in Ref. [8]. This result reflects the influence of columnar growth structure induced by slant angle deposition. The value of S for Bi-Sb film is higher than that for Sb and Bi films.

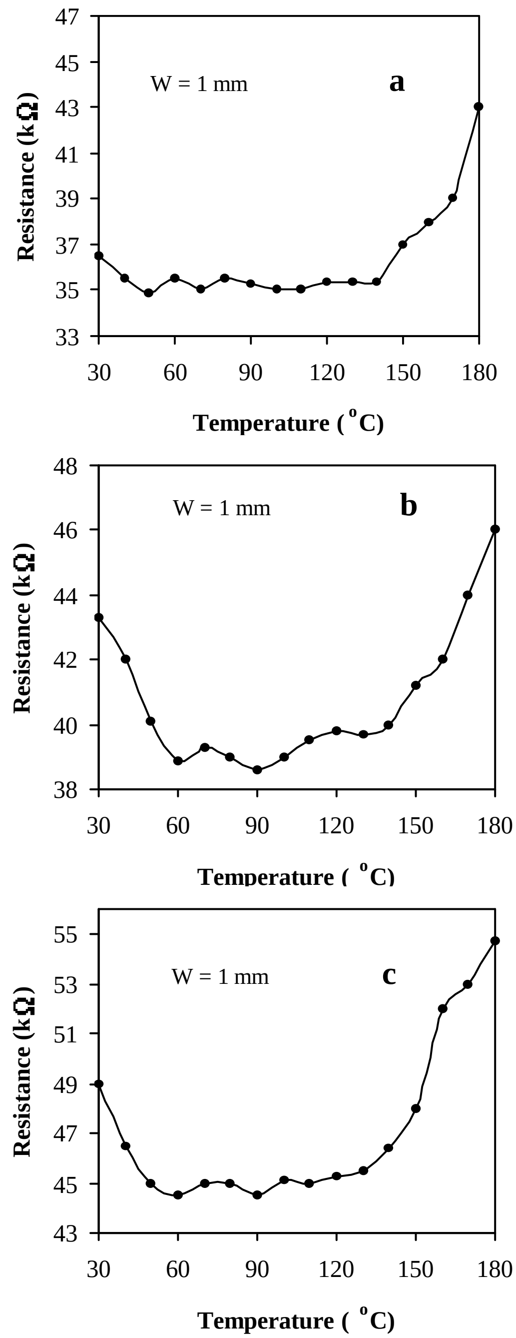


Fig. 2: Resistance versus Temperature; (a) Bi, (b) Sb, and (c) Bi-Sb.

Fig. (4) shows the responsivity of Bi detector for 1.064 µm laser pulses at different operating temperatures, the responsivity increases linearly with temperature up to 60- 75 ºC and then decreased to reach the minimum value at 120 ºC, this effect at least in part due to the reduction of defects and an isotopic stress originating from oblique deposition. On the other hand, the responsivity was higher than that reported by Akshtar and khawaja [11].

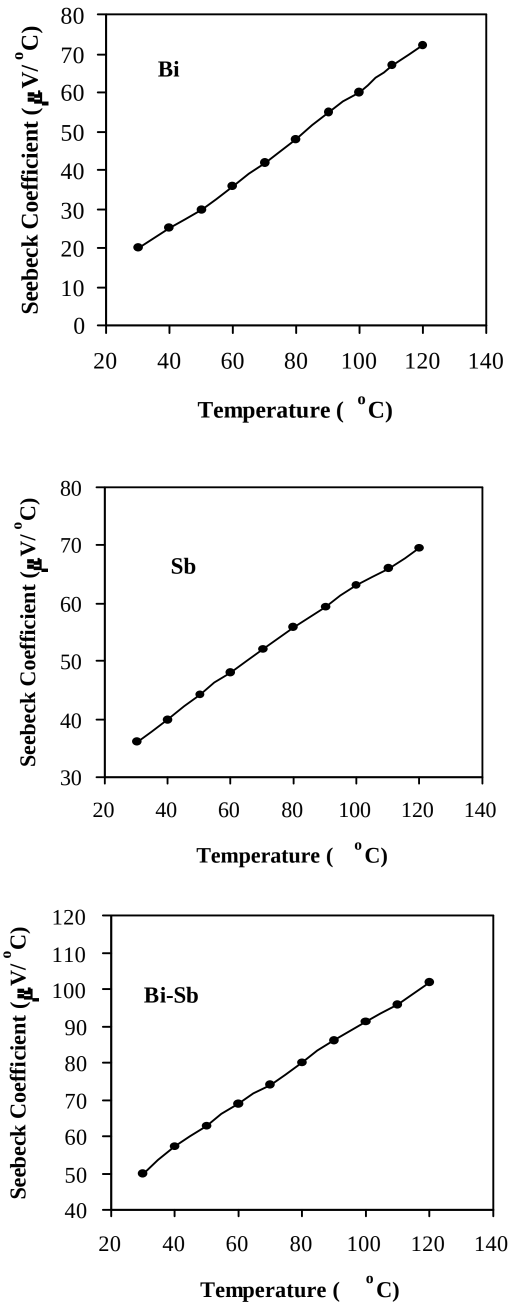


Fig. 3: Variation of Seebeck coefficient with temperature

Same effect has been obtained for both Sb and Bi-Sb detectors (Fig. 4 b and c). The responsivity of Sb detector is found to be higher than that of Bi and Bi-Sb. This is probably due to the high value of S. The effect of detector width on the responsivity is shown in Fig. 4, it is evident that the detector with small width has efficient responsivity, this result is in a good agreement with the results obtained by Gutfield [12]. Figs. (5- 7) revealed the laser pulse traces recorded by Sb, Bi and Bi-Sb detectors at different temperatures (detector with 1 mm width). The relaxation oscillation of the laser is observed in the output signal, this gives a good indication about the high speed of these detectors.

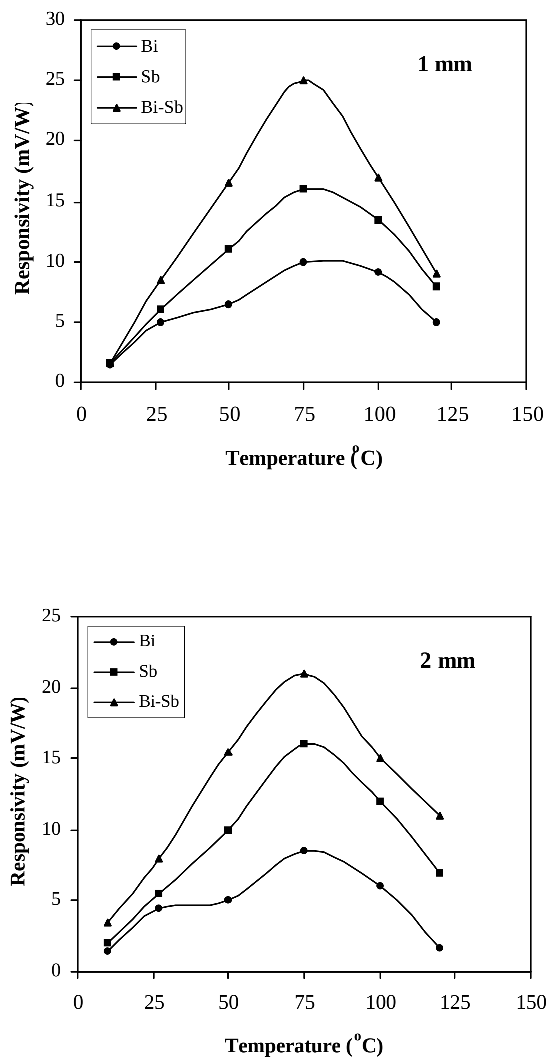
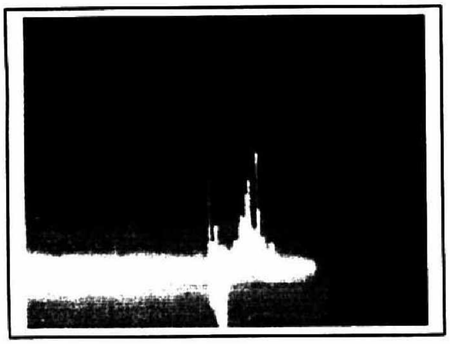
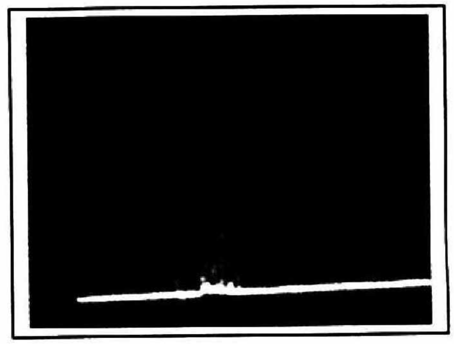


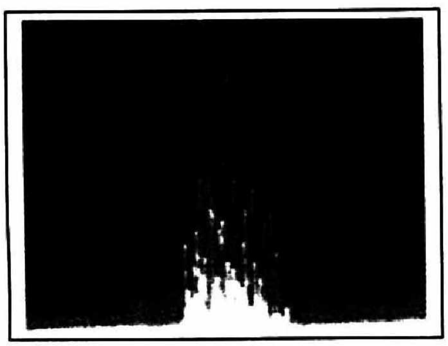
Fig. 4: Dependence of Responsivity on Operating Temperature for Different Detector Widths



T = 10 ^{o}C, Ver: 50 mV, Hor: 0.2 ms

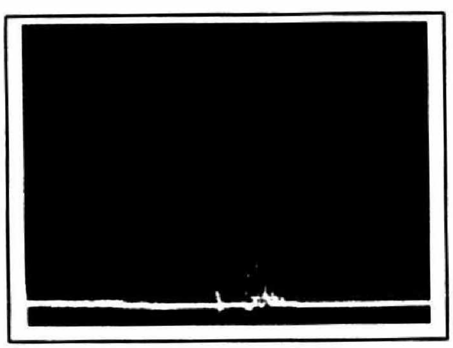


T = RT, Ver: 50 mV, Hor: 0.2 ms

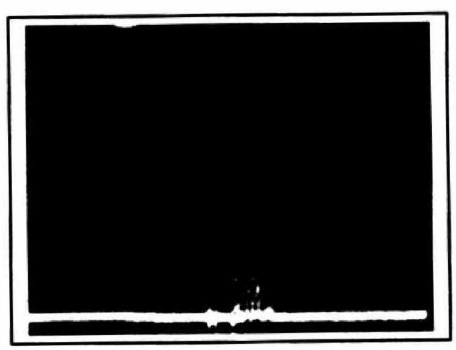


T = 50 ^{o}C, Ver: 0.1 V, Hor: 0.2 ms

T = 75 ^{o}C, Ver: 0.1 V, Hor: 0.2 ms

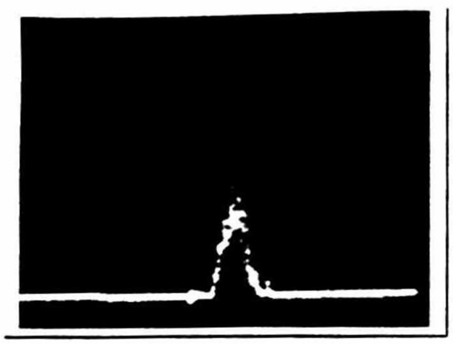


T=100^{o}C Ver : 50mV Hor: 0.2μs

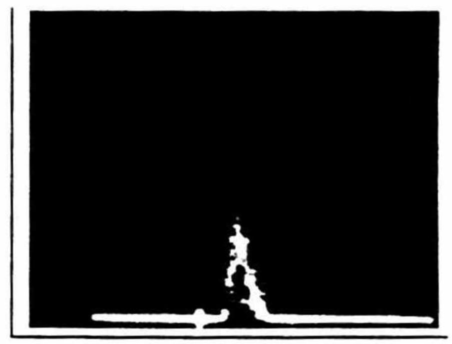


T=120^{o}C Ver : 50mV Hor: 0.2μs

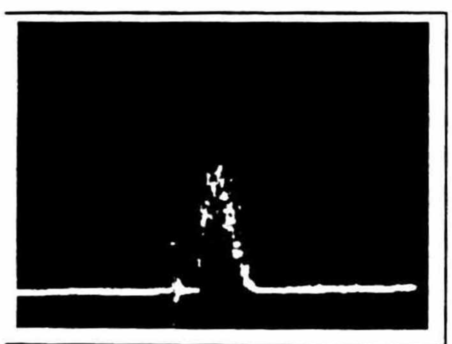
Fig. 5: Laser Pulses Recorded by Sb Detector.



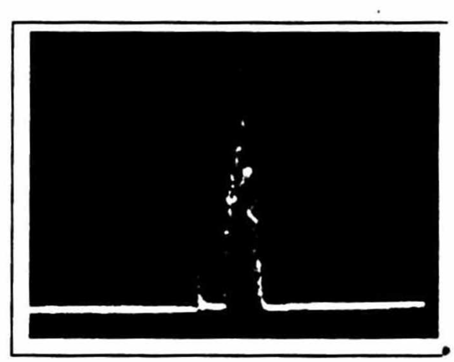
T=10°C Ver : 50mV Hor: 0.2μs



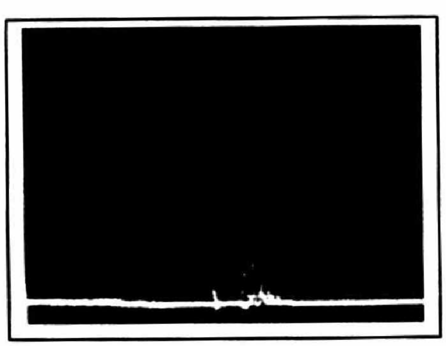
T=Room tem. Ver : 50mV Hor: 0.2μs



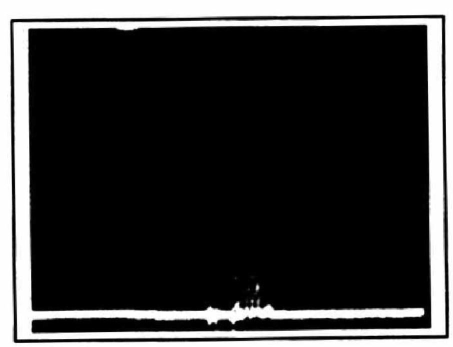
T = 50 °C, Ver: 0.1 V, Hor: 0.2 ms



T = 75 °C, Ver: 0.2 V, Hor: 0.2 ms

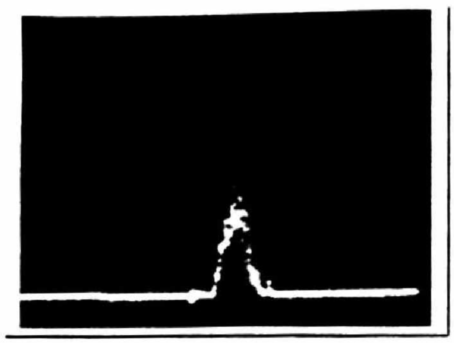


T = 100 °C, Ver: 50 mV, Hor: 0.2 ms

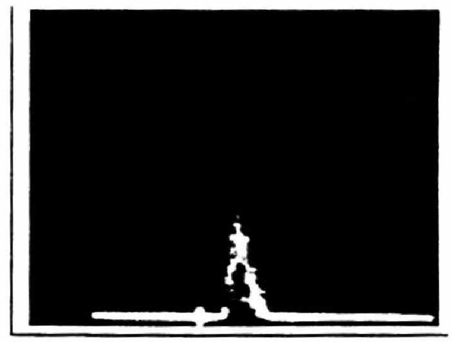


T = 120 °C, Ver: 50 mV, Hor: 0.2 ms

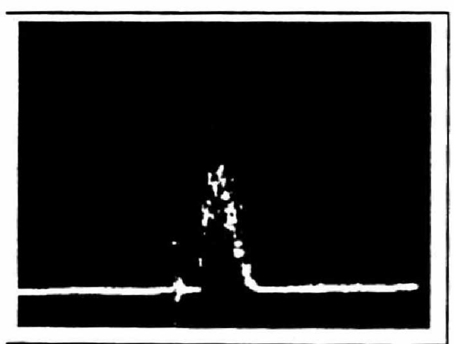
Fig. 6: Laser Pulses Recorded by Bi Thin Film Detector.



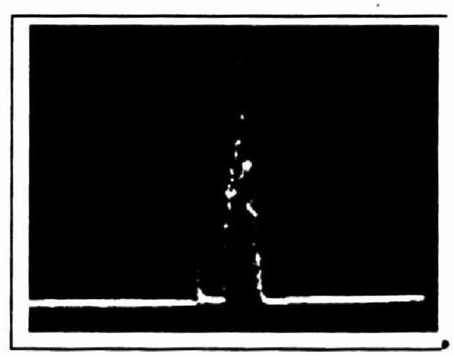
T = 10 °C, Ver: 50 mV, Hor: 0.2 ms



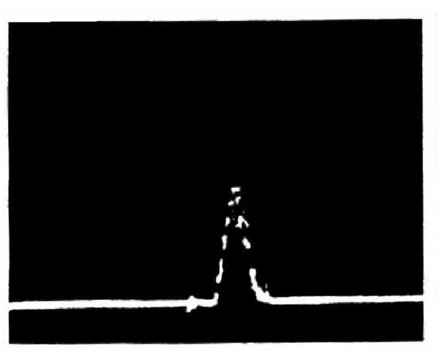
T = RT, Ver: 50 mV, Hor: 0.2 ms



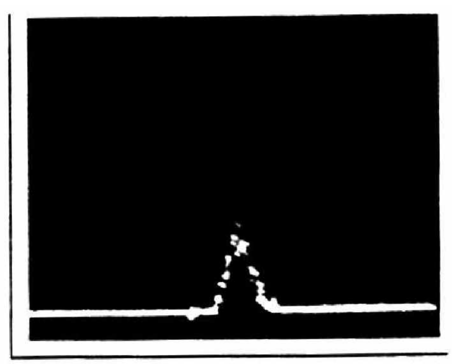
T = 50 °C, Ver: 50 mV, Hor: 0.2 ms



T = 75 °C, Ver: 50 mV, Hor: 0.2 ms



T = 100 °C, Ver: 50 mV, Hor: 0.2 ms



T = 120 °C, Ver: 50 mV, Hor: 0.2

Fig. 7: Laser Pulses Recorded by Bi-Sb Alloy Detector.

Conclusions

It has been concluded that increasing the responsivity of Sb, Bi, and Bi-Sb alloy semimetal thin film detectors for 1.064 µm laser pulses can be successfully accomplished by rising the operating temperatures. This process is negatively affecting the responsivity of conventional semiconductor detectors. The variation of rise time with detector temperature is currently underway.

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تاثير درجة حرارة التشغيل على اداء كواشــف ليزرية نوع اغشيــة رقيقــة شبه معدنية Bi و Sb و Bi-Sb المرسبة بشكل مائل

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الخلاصة

في هذا البحث تم تحضير اغشية رقيقة من Bi-Sb, Sb , Bi مرسبة بزاوية 70^0 باستخدام تقنية التبخير الحراري الفراغي . تم دراسة تغيير كل من المقاومة الكهربائية واستجابة الكواشف لنبضات ليزر Nd: YAG كدالة لدرجة حرارة التشغيل الواقعة بين ($10\text{-}120\ ^oC$) ووجد ان اعلى قيمة للاستجابية لهذه الكواشف هي عند درجة حرارة تشغيل $75\ ^oC$. من جانب اخر ، تم دراسة تاثير عرض الكاشف على خصائص الاستجابية .