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LETTER TO THE EDITOR

DETERMINATION OF SOME PERFORMANCE PARAMETERS OF MO_2S_3/Si HETEROJUNCTIONS

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The *I-V* characteristics of heterojunction (HJ) formed from thin Mo_2S_3 films and silicon wafers were studied. The measurements were carried out at different temperatures. The performance parameters as series resistance (R_s), activation energy (ΔE) of charge carriers, fill factor (F.F) and output power (P_{output}) were calculated for p/p and p/n heterojunctions. It was found thai the output power of p/n type improves slightly with further reheating.

1. Introduction

The role of carriers, diffusion and indirect optical transitions in the photo-electrochemical behaviour of layer type d-band semiconductors was studied by Keutek et al.[1]. The effect of the type of treatment of molybdenum before sulphiding on the resistance of MoS_2 coating was studied by Aparin et al.[2]. It was found from the literature that some molybdenum compounds were studied as heterojunctions for photovoltaic materials. Therefore, the study of the Mo_2S_3/Si heterojunctions are important to correlate them with those widely used materials such as Cu_2S. For this purpose, the present work aimed at the study of the *I-V* characteristics of p-Mo_2S_3/p-Si and p-Mo_2S_3/n-Si heterojunctions in order to estimate the values of some of their physical parameters.

2. *Experimental*

Pure molybdenum trisulphide (99.999%) was supplied from Coln Brook Co., England. The preparation of Mo_2S_3/Si heterojunction was achieved by the thermal evaporation of Mo_2S_3 material in a vacuum of 1.3×10^{-3} Pa. The deposition was carried out on the wafer of polycrystalline silicon at a deposition rate of 1.5 nm/s. Small squares of silicon wafers 2 mm thick were etched to remove any oxides[3-7], then they were washed with hot (368 K) distilled water and air-dried. One face of the silicon wafer was coated with aluminium layer as a bottom electrode of thickness 1.5 μm. The other face was coated with Mo_2S_3 layer with a certain thickness and an aluminium grid was evaporated by using a suitable mask to be used as a top electrode. The obtained junction area was about 0.55 cm^2.

The *I-V* characteristics of p-Mo_2S_3/p-Si and p-Mo_2S_3/n-Si heterojunctions were measured by using a suitable electric circuit comprising an oscilloscope. The measurements were carried out at different heating temperatures in the range from room temperature (R.T) to 393 K using a muffle furnace.

3. *Results and discussion*

(*i*) *I-V characteristics at different temperatures*:

Figure 1 shows the *I-V* characteristics of the heterojunctions p/p and p/n. It is observed that the forward and reverse currents increase with increasing the heating temperature. The values of the reverse current at a certain voltage are higher in case of p/n type than p/p type.

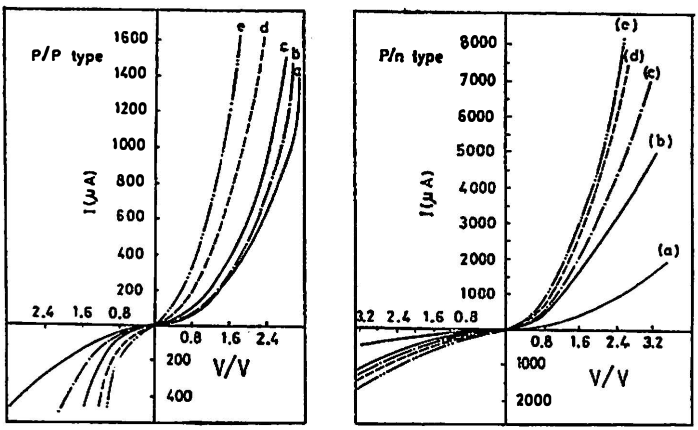

Fig. 1. *I-V* characteristics of the p/p and the p/n heterojunctions of Mo_2S_3/Si at heating temperatures:

a) Room temperature (R.T)   b) 333 K   c) 353 K
d) 373 K   e) 393 K.

The *I*-*V* characteristics of the reheated p/p and p/n heterojunctions are also studied. Both the forward and the reverse currents increased with increasing heating temperature. However, the values of the reverse current of p/n type became markedly higher after reheating.

(*ii*) *I*-*V characteristics under illumination*:

For this purpose, a small electric lamp (30 W) a meter apart was directed towards the investigated heterojunction. Fig. 2 shows the *I*-*V* characteristics of the p/p and p/n types before and after illumination for the heated and reheated samples. It is clear that a slight increase occurs in the values of the forward electric current after illumination due to photovoltaic effect. Such increase of current, photocurrent, is more remarkable in case of p/n type. On the other hand, the increase in the reverse photo-current for the p/p type is much greater than that for the p/n type. The generated photo-current is slightly weaker than that of preliminary heating. This might be due to the structural changes caused by heat treatment.

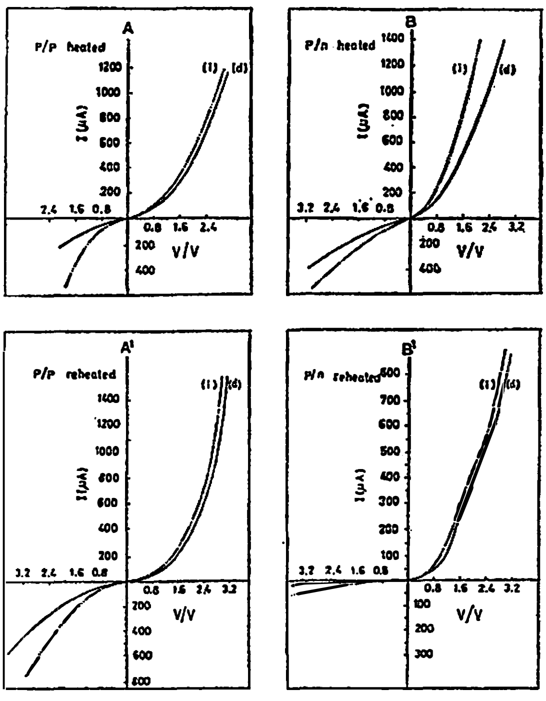

Fig. 2. *I*-*V* characteristics of heated (A, B) and reheated (A', B') Mo_2S_3/Si heterojunctions for the p/p and the p/n types in case of:
d) dark i) illumination.

(*iii*) *Determination of series resistance* (R_s):

The values of series resistance (R_s) of p/p and p/n heterojunctions were derived from Fig. 2. This was achieved by plotting ln *I* versus *V* for the exponential

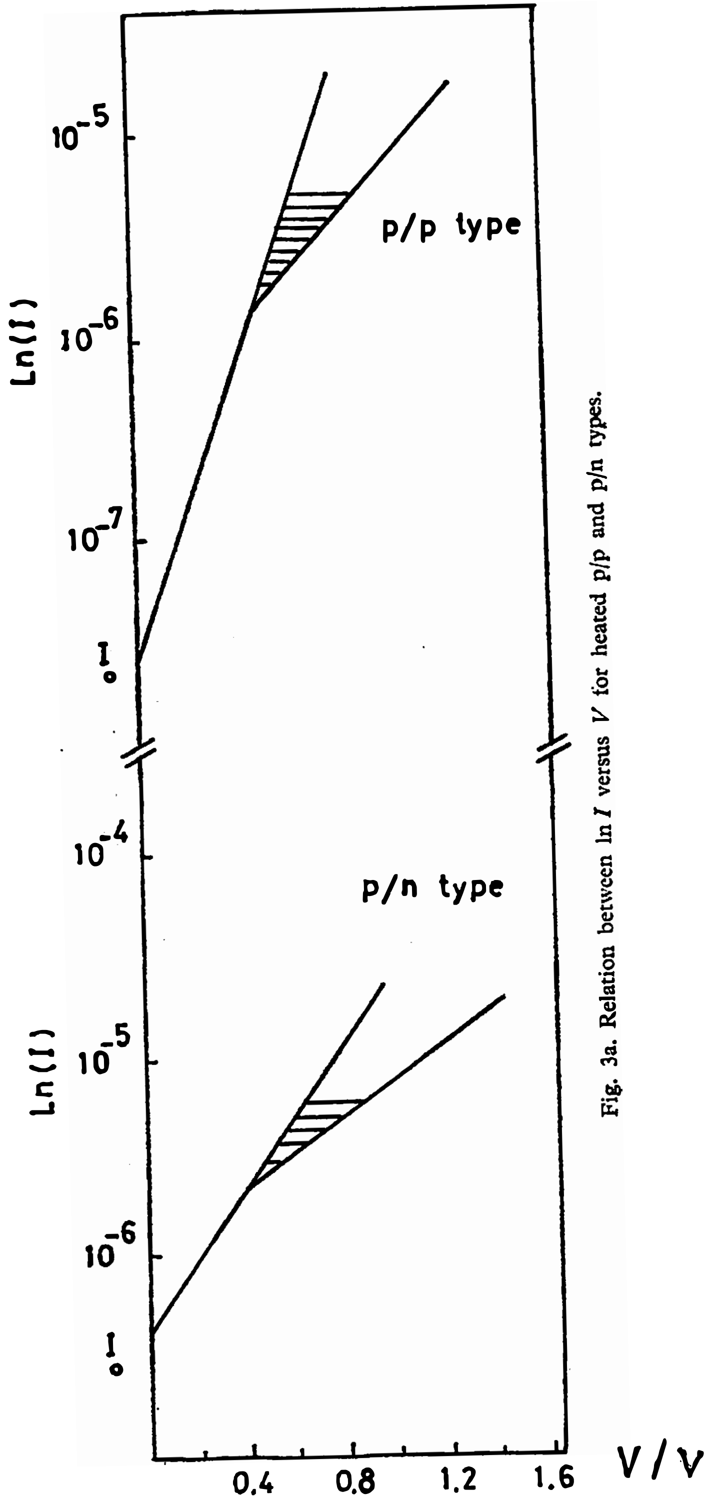

Fig. 3a. Relation between ln I versus V for heated p/p and p/n types.

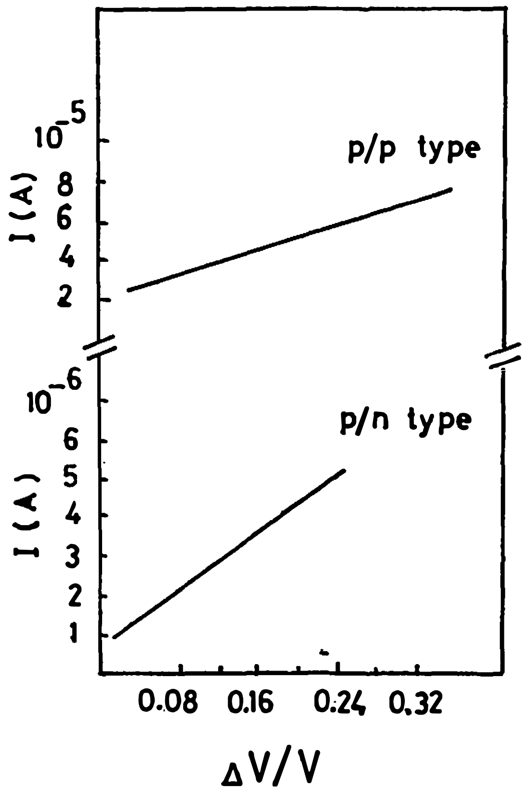

Fig. 3b. The relation between I against V foı heated p/p and p/n types.

part of the forward I-V curves; from which it is possible to find ΔV from the dashed lines [see Fig. (3a)]. Then relation between I and ΔV was plotted as shown in Fig. 3b for p/p and p/n types, respectively. The same procedure was carried out for the determination of (R_s) after reheating. The calculated results are given in Table 1.

(*iv*) *Determination of activation energy* (ΔE) *of charge carriers*:

Values of the activation energy (ΔE) of charge carriers were calculated from the slopes of the curves shown in Fig. 4 of the heterojunctions p/p and p/n for heating and reheating process, respectively. The calculated values of (ΔE) are also listed in Table 1.

(*v*) *Determination of output power* (P_{output}):

The output power (P_{output}) of the heterojunctions was determined as follows:
The output voltage V and current I were measured and plotted as shown in Figs. 5 and 6 of the heterojunctions preliminarly heated and reheated, respecti-

TABLE 1.

Performance parameters	p/p type		p/n type	
	Preliminary heating	Reheated	Preliminary heating	Reheated
R_s (Ω) [from (d) curves of Fig. 2].	1.1×10^3	1.3×10^3	1.14×10^3	2×10^3
R_s (Ω) [from Fig. (3a) and (3b)].	4×10^3	6×10^3	1.1×10^3	5.8×10^3
I_0 (A)	1.3×10^{-6}	4×10^{-6}	9×10^{-7}	3×10^{-8}
ΔE (eV)	0.396	0.146	0.113	0.189
F. F	0.310	—	0.336	0.345
P_{output} (W)	2.363×10^{-6}	—	9.032×10^{-6}	1.874×10^{-6}
μ (UV & visible regions)	0.13	—	0.51	0.11
μ (IR regions)	0.02	—	0.06	0.01

Values of series resistance (R_s), reverse diode saturation current I_0, activation energy (ΔE) of charge carriers, fill factor (F.F), output power P_{output} and efficienty (μ) of Mo_2S_3/Si heterojunctions.

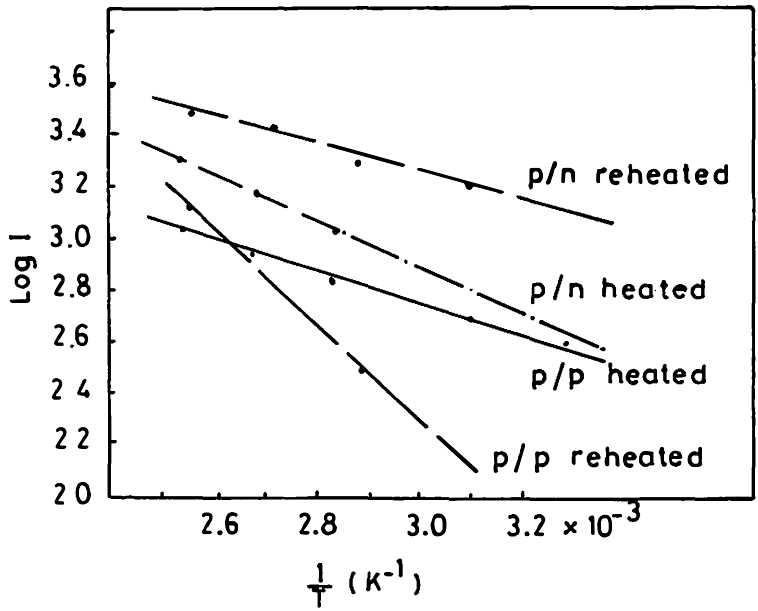

Fig. 4. Relation between log I and $\frac{1}{T}$ for heated and related p/p and p/n types.

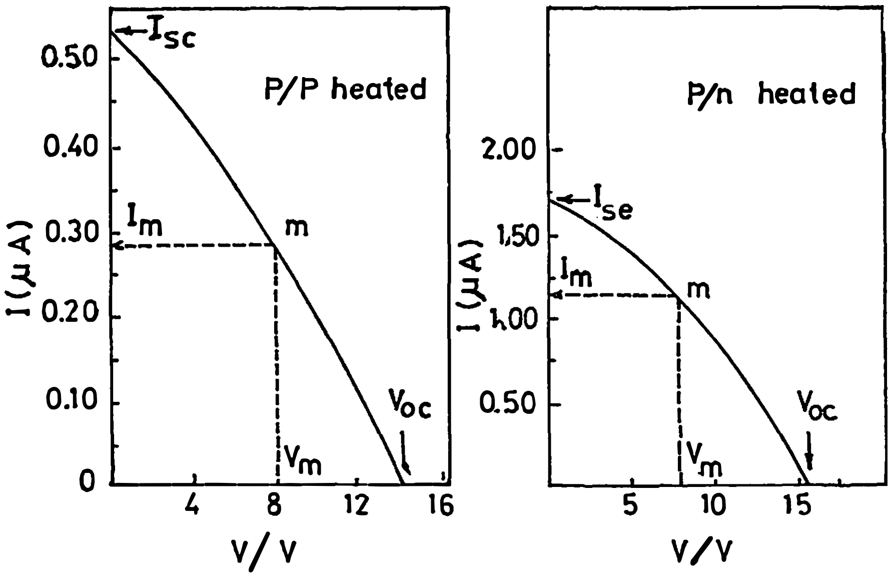

Fig. 5. Output voltage V against current I of heated Mo_2S_3/Si heterojunctions for: a) p/p types b) p/n types.

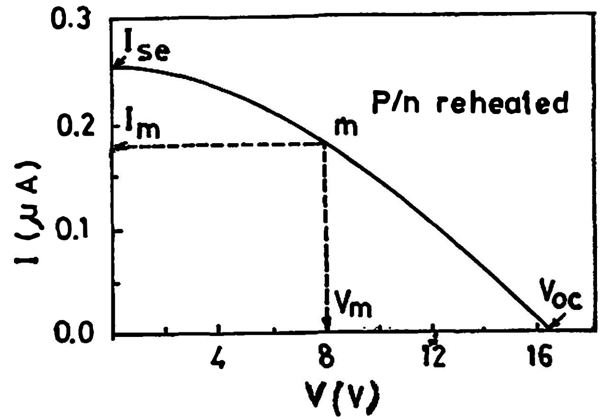

Fig. 6. Output voltage V against current I of reheated Mo_2S_3/Si heterojunction (p/n type).

vely, A rectangel was drawn in these figures from which the maximum voltage (V_m) and the maximum current (I_m) were calculated and used to obtain the fill factor ($F.F$)

$$F.F. = P_{output}/V_{oc}I_{sc},$$

where V_{oc} is the open circuit voltage, I_{sc} is the short circuit current and the output power (P_{output})

$$P_{output} = V_m I_m.$$

The calculated values of the fill factor (*F. F.*) and the output power (P_{output}) are given in Table 1. The efficiency of the p/n heterojunction was found to be 1.11 and 0.01 for ultraviolet (UV)-visible and infrared (IR) regions, respectively.

It is observed that in case of p/p type, no remarkable change of the current was indicated after reheating. This could be attributed to the decrease of activation energy (ΔE) of charge carriers for p/p type from 0.396 to 0.146 eV after reheating, whilst for p/n type, ΔE increases from 0.113 to 0.189 eV after reheating [see Table 1]. The decrease or increase of the activation energy (ΔE) could be attributed to the grain size, the distance between grains and the existence of the grain in the depleted layers. This is always accompanied by a variation in series resistance with the variation of heating mechanism. These phenomena may be attributed to the complexity of the polycrystalline structure of Mo_2S_3 films, which was already manifested by XRD and TEM analyses. This complexity is greatly reflected on the grain boundaries which may lead to the decrease in the output power.

From the present study of the Mn_2S_3/Si characteristics of p/p and p/n heterojunctions, one can conclude that much material could be used as photovoltaic substance. This was confirmed from the output power which showed reasonable value in case of p/n type after reheating. Although such value is relatively less than that obtained from other known semiconducting heterojunctions, it seems that with other schedules of heat treatment, film thickness or other experimental conditions, such output value might be improved.

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ODREĐIVANJE NEKIH KARAKTERISTIKA HETEROKONTAKTA MO_2S_3/Si

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Rad je posvećen ispitivanju *I-V* karakteristika heterospoja između tankog sloja Mo_2S_3 i silicija. Iz rezultata mjerenja izračunat je serijski otpor heterospoja, aktivacijska energija, faktor punjenja i izlazna snaga za p/p i p/n spojeve. Pokazano je da se izlazna snaga p/n spoja blago povećava zagrijavanjem.