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Abstract.- A p-n heterojunction was prepared by depositing a thin film of p-type amorphous $As_2Se_3Cu_x$ (x = 0.2, 0.4 and 1.0) on n-type crystalline silicon wafers. The I-V characteristics of the junction were typical of those of p-n junctions both in the dark and under illumination. The preliminary optimum characteristics were obtained with an annealed p-type amorphous $As_2Se_3Cu_{0.4}$ with an optical gap of 1.43 eV. A maximum open circuit voltage (V_{oc}) of 0.37 V and short circuit current (I_{sc}) of 10 mA/cm^2 was observed under solar radiation of 800 w/m^2.

Introduction.- In the amorphous As, Se, Cu system it was found that the electrical conductivity can be varied from that of an insulator to a metal depending on the concentration of copper(1). These changes in electrical conductivity are accompanied by substantial changes in the mobility gap which suggests that one can choose any conductivity and mobility gap that one needs over a relatively wide range. In addition, all the compositions studied in this system were p-type semiconductors.

Due to these encouraging properties, we attempted to check the feasibility of making a solar cell of chalcogenide $As_2Se_3Cu_x$ glass on crystalline n-silicon heterojunction. Not all the parameters of such a junction can be optimized due to the great number of variable that one encounters. These include the concentration of copper (value of x), chalcogenide film thickness, type of contact, heat treatment and others. In this paper, only a few parameters were checked and the results were encouraging but not ideal.

Preparation and Properties of $As_2Se_3Cu_x$.- Appropriate ratios of high purity As, Se and Cu were heated in fused silica at 950°C under vacuum for about 6 hours. Detailed description of preparation conditions was described elsewhere(2). Since all the three prepared compositions $As_2Se_3Cu_x$ (x = 0.2, 0.4 and 1.0) contained copper less than 28 at.%, they were all obtained in the amorphous state.(1).

Sandwich electrode configuration with two ohmic contacts was used to investigate the dark conductivities in the temperature range 70 K up to 400 K at low electric fields of 10-100 V/cm. Photoacoustic technique using powdered samples as well as optical absorption technique for amorphous films were used to measure the optical gap Eg (E_c - E_v). The results of dark conductivity and optical measurements for the investigated amorphous materials are given in the following table.

No.	Composition	at % copper	$-\log\sigma/20^{\circ}C$	E optical $(E_c - E_v)$	E Thermal $(E_f - E_v)$
1	$As_2Se_3Cu_{0.2}$	3.9	8.7	1.50	0.57
2	$As_2Se_3Cu_{0.4}$	7.4	6.9	1.43	0.49
3	$As_2Se_3Cu_1$	16.4	4.6	1.30	0.36

Since all copper containing samples are p-type, the main current is carried out by holes and thermal activation energy is given by (E_f-E_v) in the expression:

$$\sigma = \sigma_o \exp - (E_f - E_v)/kT$$

All the conductivity versus temperature curves were found to exhibit one slope in the temperature range studied. The choice of these compositions for the preparation of the heterojunction was decided because their optical gaps match well with the maximum solar distribution and at the same time their electrical conductivities are intermediate between highly conducting doped semiconductors and poor conducting amorphous materials. At the same time since the amorphous film will serve as a window in the heterojunction, its optical gap must be greater than the optical gap of the n-Si absorber (3).

Preparation of the Heterojunctions.- N-type crystalline silicon 200 µm wafers (ρ= 1-3 ohm-cm) were etched and cleaned with the proper reagents and then dried. A thick aluminum film was deposited on one surface of the wafers which served as the back contact. The wafers with the aluminum contact were annealed in a nitrogen atmosphere at 200°C for about 30 minutes. The other surface of the silicon wafers was again etched and cleaned. This was followed by depositing amorphous $As_2Se_3Cu_x$ (x = 0.2, 0.4 and 1.0) film whose thickness ranged from 300 to 3000 Å. A thin transparent gold film was then deposited on the amorphous material followed by a gold grid which served as a front contact. I-V characteristics for the prepared heterojunctions were plotted both in the dark and under illumination. In laboratory measurements a xenon lamp (1 KW power) was used as a light source, but in some other measurements direct solar radiation was used whose intensity was about 800 w/m^2.

The I-V Characteristics.- Although the I-V characteristics varied from device to device, all showed the same general behavior. The I-V characteristics were found to be highly dependent on the composition of the amorphous window and its thickness. The best illuminated I-V characteristics of the heterojunctions with p-type amorphous layer with minimum copper content (sample 1 in table with Eg=1.5 eV and $\rho/20^{\circ}C = 5 \times 10^8$ ohm-cm) gave an open circuit voltage of 0.26 V and short circuit current of 2.7 mA/cm^2 under laboratory conditions (2400 w/m^2). The thickness of the amorphous layer in this junction was about 1200 Å. The heterojunction containing the maximum copper content amorphous layer (sample 3 in table with Eg = 1.3 eV and

$\rho/20^{o}C = 4 \times 10^{4}$ ohm-cm) gave under the same laboratory illumination conditions $V_{oc} = 0.24$ and $I_{sc} = 2.4$ mA/cm^2. The thickness of the amorphous layer in this junction was the same as in the junction with minimum Cu content. The best illuminated I-V characteristics were noticed for the heterojunction with p-type amorphous layer with 7.4 at. % Cu (sample 2 in table) with Eg = 1.43 eV and $\rho/20^{o}C = 8 \times 10^{6}$ ohm-cm and a thickness ranging between 1200 - 1500 Å. These characteristics are given in the following figure under laboratory illumination conditions.

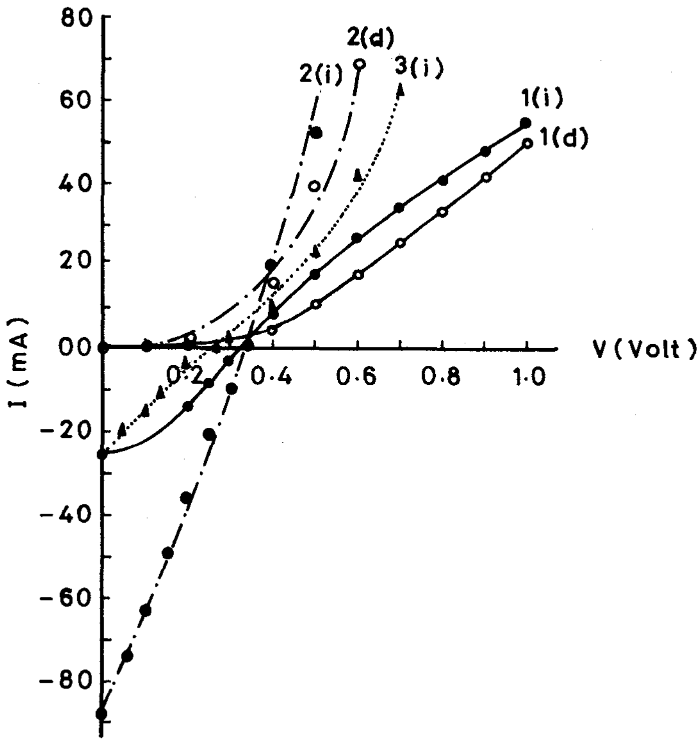

Figure.- The dark (d) and illuminated (i) I-V characteristics of the p-type amorphous $As_2Se_3Cu_{0.4}$ -n-type crystalline silicon before annealing (curves 1(d) and 1(i) and after annealing (curves 2(d), 2(i) and 3(i)).

Area of the sample = 2.7 cm^2

Light intensity = 2400 w/m^2

In this figure the dark and illuminated I-V characteristics are given by curves 1(d) and 1(i) respectively. From these curves we noticed that V_{oc}=0.37 V and I_{sc}=23 mA/2.7cm^2=8.5 mA/cm^2. We believe that proper thermal annealing of the junction may improve the I_{sc}. When this sample was annealed for a maximum period of 30 min. at 100^{o}C in nitrogen atmosphere we noticed large changes in the I-V characteristics. This is given by curves 2(d) and 2(i) in the figure for dark and illuminated characteristics respectively. The illuminated V_{oc} was the same as before annealing but the I_{sc} increased by a factor of 3.7 after annealing for 30 min. The value of the short circuit current was 83 mA/2.7 cm = 30.7 mA/cm^2. When this sample was checked under solar radiation of 800 w/m^2 intensity the V_{oc} was .37 V and I_{sc} = 10 mA/cm^2. This was the best characteristics obtained for all the studied heterojunctions. Further thermal annealing of this sample for 30 min. at 200^{o}C in nitrogen atmosphere was carried. A large decrease in the V_{oc} as well as in I_{sc} was noticed (curve 3(i) in figure).

Conclusion.- From these results, it seems feasible to make a heterojunction solar cell of p-type amorphous $As_2Se_3Cu_x$ and n-type silicon. The ideal cell characteristics will depend on many variables that have to be optimized independently and collectively, which require extended research on this subject.

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