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Date: 12th Sept., 2001.

Dr. O.U. Oparaku,
Dept. of Electronic Engineering,
University of Nigeria,
Nsukka.

Dear Dr. Oparaku,

ACCEPTANCE OF PAPER FOR PUBLICATION

I am pleased to inform you that your paper titled: "Development of an Electroplating System for Thickening Solar Cell Ohmic Contacts" has been accepted for publication in Nigerian Journal of Technology.

The paper will appear in the next issue of the Journal.

Best wishes.

Yours faithfully,

Engr. Prof. O.J. Eze-Uzomaka
Editor-in-chief (NIJOTECH)

(9)

DEVELOPMENT OF AN ELECTROPLATING SYSTEM FOR THICKENING SOLAR CELL OHMIC CONTACTS

By

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ABSTRACT

A novel technique developed for thickening the front and back contacts of solar cells simultaneously by the electroplating process is presented. Pre-plating optimisation procedures adopted to obtain electroplated films of Ag with good adhesion, appearance and resistivity are discussed. The surface morphology and resistivity of the plated films were obtained and the application of the technique for thickening the front and back contacts of Indium Tin Oxide/Indium Phosphide(ITO/InP) Solar Cells is described.

1. INTRODUCTION

Indium phosphide(InP) has attracted much attention because of its wide use in the fabrication of laser diodes and detectors and for solar cells(1,2).
Because of its high radiation resistance, it is a good material for solar cells used in powering space satellites. The ITO/InP structure possesses optical and electronic properties that make it well suited for solar cell applications. The Indium Tin Oxide(ITO) serves as a window layer, enabling a wide spectrum of the incoming solar radiation to be admitted into the InP absorber layer. Prior to this work, a gold-wire mesh fastened to the ITO surface with sellotape, served as the front contact. The gold-wire mesh which was used for the initial performance testing of the cells, is not suitable for commercial cells where engineered contacts are required. The Zinc/Gold(Zn/Au) alloyed back contact to the ITO/InP cell is typically 0.3μm thick. To obtain engineered solar cells with commercial viability, both the front and back contacts have to be thickened to about 5μm so that they can be reliably bonded to interconnecting wires or foils. Moreover, thickening the contacts reduces their effective resistivity.

The electroplating process(3) is favoured for thickening the contacts because, unlike vacuum deposition and other techniques, it is inexpensive and requires simple equipment. In addition, wastage is minimised since the deposit precipitates where it is required.

Silver (Ag) plating has made significant impact in both decorative and engineering applications. The latter has sought to harness the excellent mechanical and electrical properties of silver. For electrical and electronic engineering-based applications, the high conductivity of silver is an important consideration. Although the conductivity of thin films of silver does not equal the theoretical conductivity of bulk silver, it is still higher than that of most metals. Besides its high conductivity, silver is, for this work, chosen as a good material for thickening the contacts because it has been space-qualified for reliability(4).

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2. EXPERIMENTAL

The factors considered in setting up the plating system included the design of a suitable jig to hold the substrates and the choice of equipment and chemicals for the strike and plating baths. The silver plating process was first optimised before it was used to thicken the front and back contacts of 4cm^2 ITO/InP solar cells with efficiencies between 13-14%(5). The electroplated films were characterised to obtain their surface morphology, adhesion and electrical resistivity.

The jig design, the plating system and optimisation processes are presented.

2.1 Description of the Jig

The components of the jig are shown in Figure 1. The components A,B_1,B_2 and C are coupled as shown. E is inserted through the arms of D up to the level A - A. B_1 and B_2 are coupled to D through the eight holes. A metal strip is stuck to the shedded portion of E and made to protrude about 1mm beyond the edge marked X. The substrate to be plated is placed on the shedded recess in D to make contact with the 1mm protruding portion of the metal strip on E. Another metal strip is placed on the other side of the substrate to make contact with about 1mm of its edge. Proper ohmic contact between the metal strips and the substrate is achieved by placing F to fit the recess in E and fastening both E and F together by means of screws through the eight holes.

The jig, made from perspex material, holds the substrate firmly so that it does not fall into the plating solution which is being constantly agitated. It allows a good ohmic contact between the substrate and the metal strips which serve as the cathode, and is suitable for plating Ag simultaneously on the front and back contacts of ITO/InP Solar Cells. It can also be used to electroplate solar cells based on other semiconductor materials but is unique in its ability to hold very fragile materials like InP, without breakage.

2.2 Plating System and Optimisation Process

The plating system consists of a strike bath and a plating bath, both containing silver cyanide (Ag CN) plating solutions of different concentrations, a dc power supply, a magnetic stirrer for constant agitation of the solution and high-quality Ag electrodes with purity of 99.99%. The strike bath contained 4g/l of Silver Cyanide(AgCN) and 70g/l of Potasium Cyanide(KCN) as it has been shown that a silver cyanide solution alone does not produce a very adherent deposit. The plating bath contained 30g/l AgCN and 100g/l KCN. Additional agents such as potassium hydroxide (10g/l of KOH) were added to improve conductivity and hardness of deposited films - KOH aids in preventing breakdown of cyanide by maintaining an alkaline PH.

In view of the high cost of InP substrates, initial experiments aimed at improving physical appearance, adhesion and at optimising the thickness of the plated films were performed with silicon substrates coated by vacuum evaporation with gold or silver or aluminium and with substrates consisting of RF-sputtered Ag and ITO on glass. The conditions for the striking and plating processes are shown in Table 1.

The substrates were degreased and rinsed in deionised water before mounting in the jig. After plating, the cathode was cleared with a jet of deionised water and given liberal rinses in both cold and warm deionised water before it is blown dry with N_2 gas. The substrates were subsequently cut into samples which were characterised. The surface morphology and resistivity of the plated films were obtained with scanning electron microscope and four-point-probe techniques respectively. Thicknesses of the plated films were measured with a Taylor-Hobsons Talystep equipment. Photolithography and dilute ferric nitrate etch were used to generate the steps required for the thickness measurements. A specific contact resistance at the Ag/ITO interface was obtained by the transmission line model (TLM) technique(6). ITO/InP solar cells with Zn/Au back contacts were electroplated after an R.F sputtering of 1000Å of Ag on the ITO, to prevent chemical attack of ITO by the plating solution which occurs if an attempt is made to plate Ag directly unto ITO.

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3. RESULTS AND DISCUSSION

All samples plated using the three current densities had a good silvery finish with no traces of plating defects such as pits or cracks, in compliance with specifications (7). SEM micrographs (Plates A and B) revealed the sizes of the grains and show that the surfaces of samples plated at the higher current density are more granular. Good uniformity of appearance was observed on all the samples.

Post-plating assessment of the film adhesion using the sellotape test revealed that the adhesion at the Au/Si and Ag/Si interfaces were poor. With an Al/Si substrate, the aluminium reacted with the plating solution. This reaction is assumed to be due to the high position of Al in the electromotive force series and its relatively impervious and rapidly formed natural oxide films (8). For the Ag/ITO structure, good adhesion was obtained when ITO and Ag were deposited by magnetic sputtering in the same run, without breaking vacuum. At the three current densities (Low, Medium, High), the thicknesses of the films in μm were 5.80 $\pm$ 0.42, 6.10 $\pm$ 0.26 and 6.50 $\pm$ 0.79 respectively. The plating at medium current density is favoured because it has a shorter time of plating compared with the low current density and gives films whose thicknesses are closer to the required value (5μm) compared to the plating at high current density. A value of 2.20 + 0.02 x 10^{-8} ohm.m for the resistivity was obtained. The specific contact resistance of the Ag/ITO interface measured on several samples lied in the range 1.4 x 10^{-7} ohm.m^2 and 3.5 x 10^{-8} ohm.m^2. The linearity of the I-V characteristic measured at the interface between the front contact and the ITO layer shows ohmic behaviour at the interface (Figure 2). For cell production purposes plating at the medium current density is favoured for the reasons given above, in addition to the fact that it offers a smoother film surface than the plating at high current density. The jig met the requirements of plating about 5μm of Ag on the front and back contacts of the cells in the same run. Scratch adhesion tests showed that the adhesion of the plated films was good. The engineered cells produced as a result of the development of this electroplating system were tested for terrestrial and simulated space degradation (9,10) and found to be stable after several months of storage and irradiation.

CONCLUSION

A plating system has been successfully developed for thickening the front and back contacts of solar cells simultaneously. This system has been used to thicken the contacts of ITO/InP solar cells to about 5μm thus facilitating the bonding of wires and interconnections to the contacts and enabling degradation studies to be performed on the cells.

Acknowledgement

The assistance of Mr. I. Forbes in producing the cells is highly acknowledged. The authors appreciate the role of the Royal Aerospace Establishment, U.K., as sponsors of the work.

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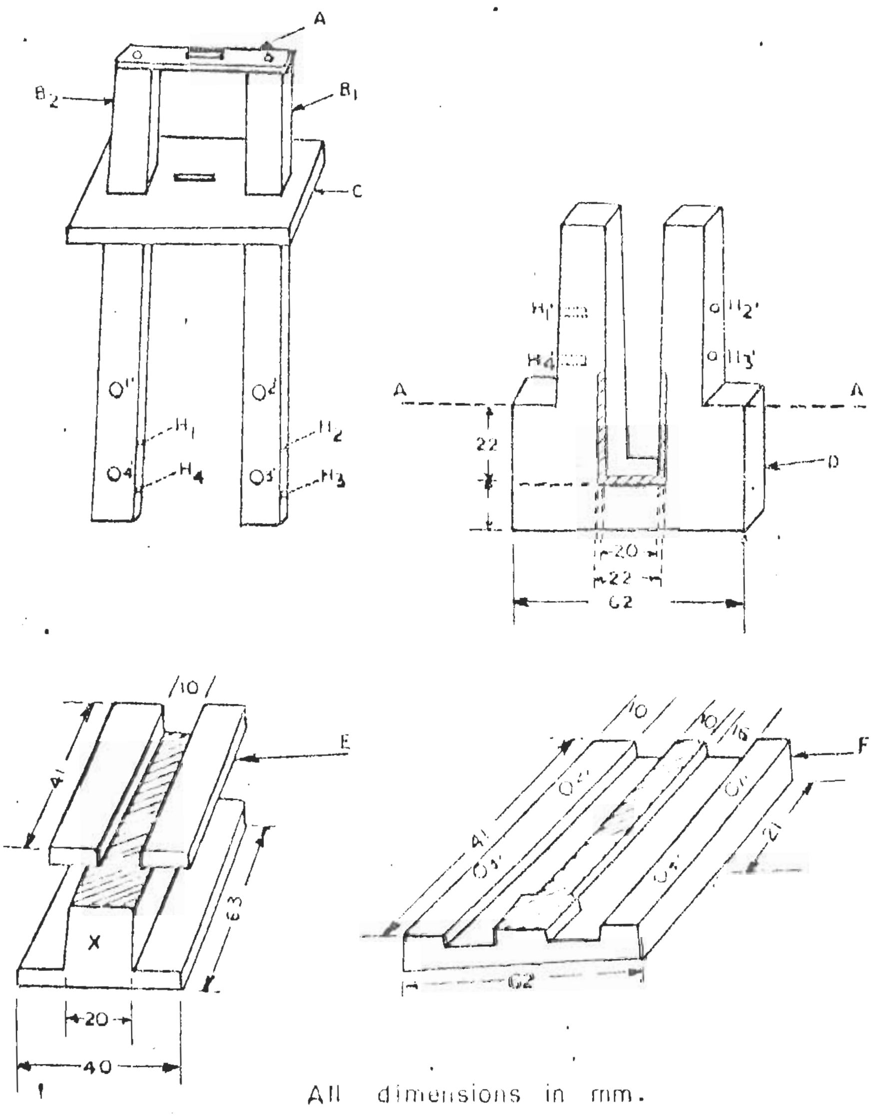
Table 1: Conditions for Striking and Plating

Striking Current (mA)	DC Voltage (V)	Time (Sec.)	Plating Current (mA)	DC Voltage (V)	Time $x10^3$(sec)
20	2	20	15	2	2.4
40	2	20	30	2	1.2
80	2	20	60	2	0.6



All dimensions in mm.

Figure I. Jig design for Plating on 2cm x 2cm Semiconductor Substrates

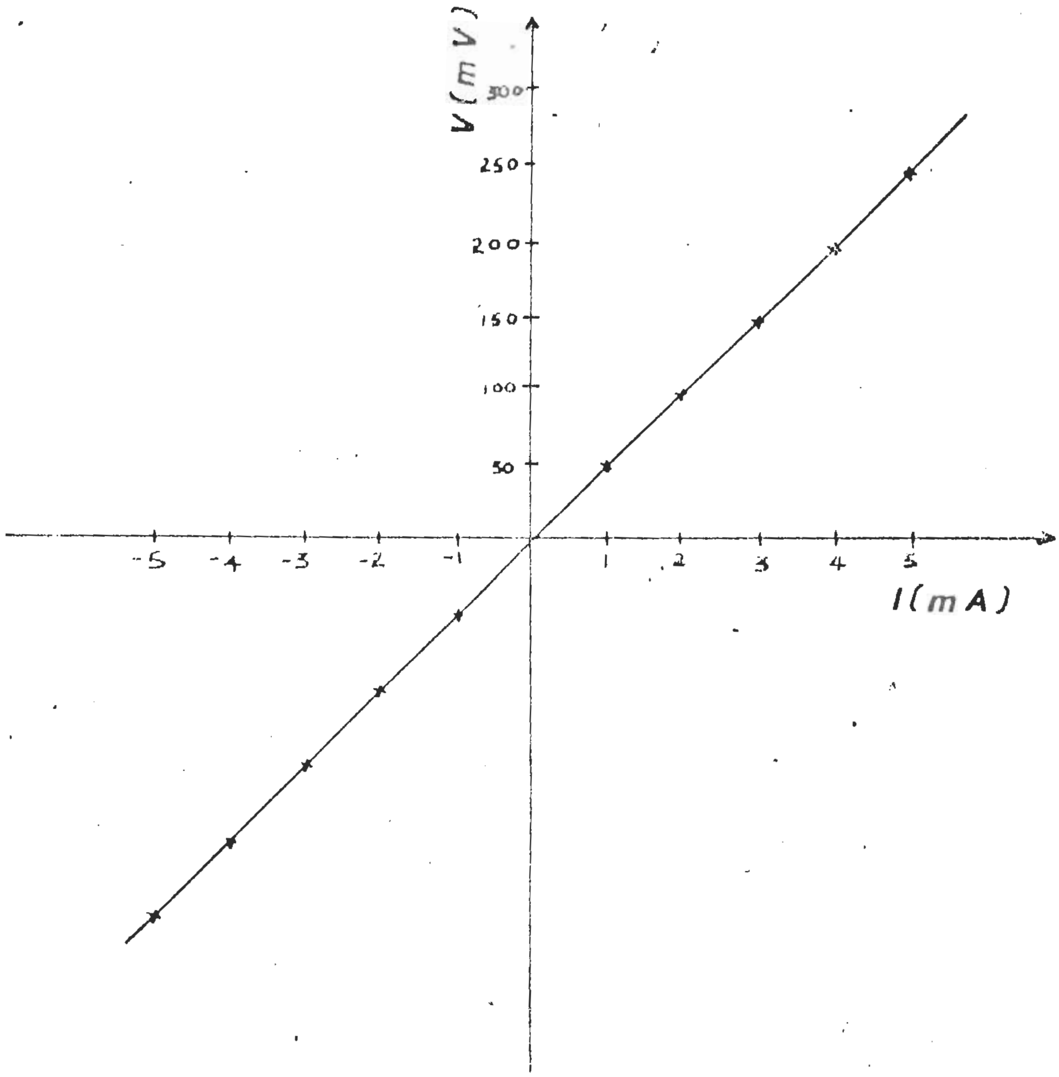
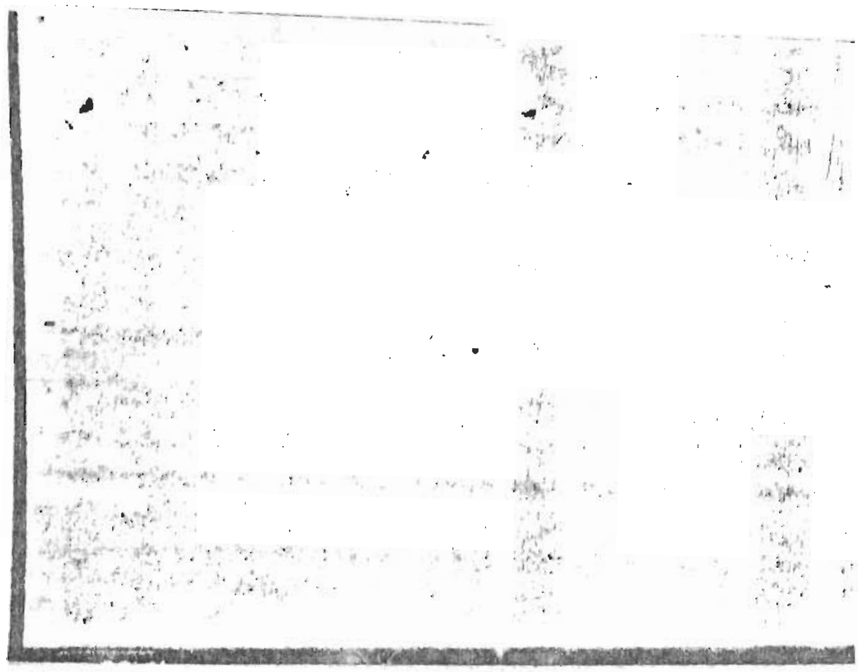
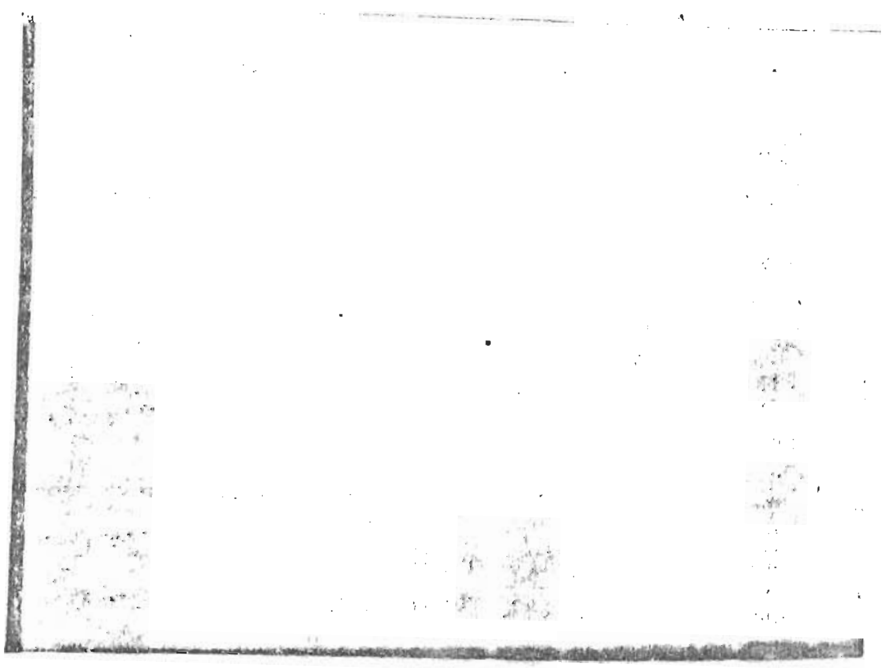


Figure 2: Linearity of the I-V characteristics of electroplated silver layers on ITO



LATE A: SEM Micrograph of films deposited at the medium current density.



LATE B: SEM Micrograph of films deposited at the high current density.