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EMERGING MATERIAL SYSTEMS

FOR SOLAR CELL APPLICATIONS

W. J. Biter and J. R. Szedon

Technical Progress Report No. 1
For Period 16 April 1979 to 16 July 1979
Contract No. DE-AC04-79ET23003

August 8, 1979

Westinghouse R&D Center
1310 Beulah Road
Pittsburgh, Pennsylvania 15235

DISCLAIMER

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1. PROGRAM OBJECTIVES

The aim of the present program is to develop an InP/CdS polycrystalline thin film solar cell. Preliminary modelling of an idealized thin film photovoltaic array has shown that the InP/CdS system should be capable of at least 10% array efficiency at costs below $0.30/peak watt. The major technical problem is determining whether material interaction effects which occur during growth, particularly as affecting the InP grain boundaries, can be controlled to permit cell conversion efficiency to approach the 15% value demonstrated in the single crystal case.

The program is divided into five tasks. These tasks are:

(1) Modelling of photocurrent collection, cell performance and cell processing to improve performance and to project cost and material usage.

(2) Growth of InP films on various substrates.

(3) Characterization of physical and electrical properties of the produced films.

(4) Cell preparation using the thin films of InP as well as single crystal InP.

(5) Cell analysis to evaluate and characterize the above devices.

In the initial part of the program, the major emphasis will be on InP film growth and preparation and on determining the suitability of the electrical, optical, and other characteristics of the films for solar cell applications aimed at meeting the program goals. InP films will be prepared on a series of substrates (single crystal InP wafers, single and polycrystalline CdS wafers, and CdS thin films) by a number of methods.

Plasma-induced deposition (PID) will be explored as a means of avoiding the material interactions at high temperature associated with evaporation and thermally-driven chemical vapor deposition. The PID system will be operated in a reactive sputtering mode to assess the quality of films by a potentially less expensive, large area deposition method. Characterization of films and of solar cell structures will be done to establish film quality and appropriateness for solar cell applications.

2. PROGRESS

The effort to date has been primarily on modifications and additions to the vacuum system in order to produce films of InP by the PID process. The initial setup will transfer the indium to the chamber using triethyl indium (TEI), while phosphorus will be introduced from a mixture of PH_3 and argon. An indium target, consisting of a few microns of indium evaporated onto an oxidized silicon wafer, will be mounted on the rf sputtering head. The entire system has been assembled and checked out. A number of initial runs were made involving plasma etching of single crystals of InP using $SiCl_4$ as the etching gas. This was done to demonstrate operation of the system and to evaluate methods of in-situ cleaning of the InP.

2.1 Film Growth

Plasma-induced deposition is a process of film growth in which the material to be deposited is introduced in the form of one or more gaseous compounds and the energy required to dissociate the compounds is supplied from the plasma. One of the main advantages of this process is the ability to produce films at low substrate temperatures. Conventional CVD processes use the temperature of the substrate to pyrolytically decompose the gases. At low substrate temperatures deposition efficiency is very low. In the plasma process the temperature of the film, while determining the structural type of film growth, has relatively little effect on the rate of deposition, and films can be grown with the substrate at low temperature. The method described in this report uses a

hybrid system which involves both the plasma decomposition of the vapor transported material and some amount of direct physical deposition by sputtering. This should add some flexibility to film formation.

A system has been assembled for use for this program. It is a stainless steel, bakeable system which is capable of UHV operation ($< 10^{-8}$ Torr). The main pumping system consists of a 500 ℓ/sec ion pump and a LN_2 cooled Ti sublimation pump. This is used for initial pumpdown of the apparatus and bakeout, if needed, to reduce the amount of background water vapor. A 100 ℓ/sec turbomolecular pump, backed by a mechanical forepump which is vented directly to the exhaust system, is used for the actual deposition. This system is shown in Figure 1. In operation, the turbo pump is valved off so as to hold the pressure at its input to about 10 to 20 mTorr, which is the maximum operating pressure for the turbo pump. The total pressure system is controlled by the gas flows into the chamber. The throughput at these pressures is limited by the mechanical pump; using a Welch 1397 this should be in the range of 10 to 20 cm^3/min (STP), depending on the pressure at the exhaust of the turbo pump. This should allow adequate control on the input gases.

Flowmeters (glass rotometers) are used to control the flow of the various gases into the system. Since there are a number of gases introduced into the system, accurate and precise control of the gas mixture is essential. Ultimately, it would be desirable to replace these rotometers with mass flow controllers which are not sensitive to the pressure. This is only a problem with gases whose source pressure is below atmosphere, such as the triethyl indium (TEI). The TEI is obtained as a relatively low vapor pressure liquid (below 1 mm pressure at RT). There are two options for transferring the TEI into the vacuum system. The first involves direct connection to the system and pumping on the liquid. Due to the low vapor pressure of the TEI, this approach requires a high conductance connection between the vacuum system and the TEI bottle in order to achieve the required throughput of gas. The second approach is to use a carrier gas which is bubbled through the TEI. This relaxes the requirements on the size of the connection to the vacuum system (and

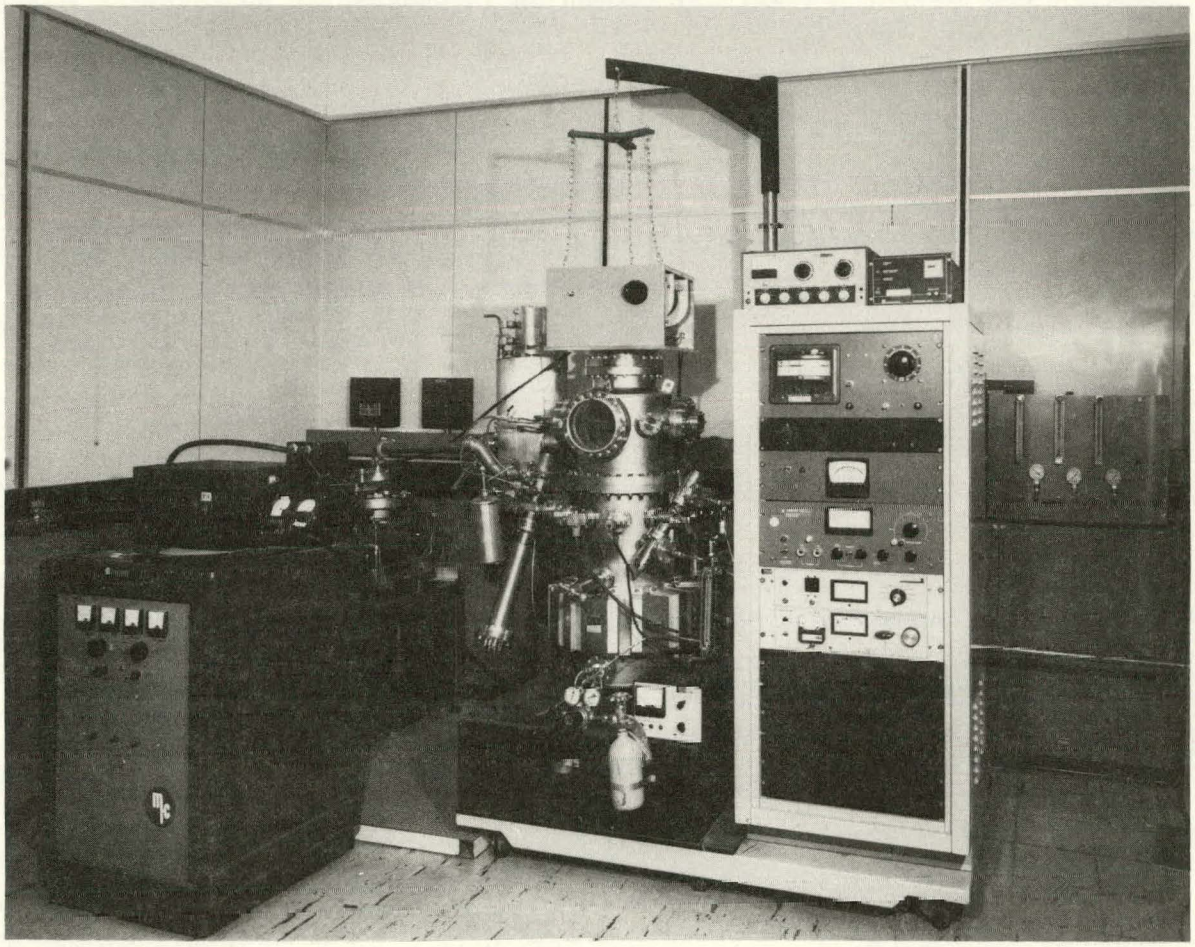

Fig. 1. UHV system for plasma induced depositions.

improves the accuracy of the flowmeter), but introduces the complication of pumping the carrier gas. The initial depositions will be made with the TEI attached directly to the vacuum system and the flow rate monitored using the total system pressure.

The system also has been equipped with a quadrupole mass analyzer (QMA) [UTI Model 100C]. Since this unit will operate only at pressures below 10^{-4} Torr, it is necessary to provide a separate pumping system to maintain the pressure in the head while the deposition system is being operated at higher pressure, e.g., 500 mTorr. This is accomplished by using a separate turbomolecular pump to evacuate the QMA head while a small quantity of the gas from the chamber is sampled through a leak valve.

The sputtering head is a water-cooled rf sputtering target holder mounted on a copper-sealed flange. It is used to generate the plasma. It can also be used in a conventional sputtering mode for the direct physical deposition of the target material. The target itself is a 3-in. dia. disc which screws into a water-cooled holder. The sputtering head is shown in Figure 2.

The substrate heater consists of a water-cooled copper reflector in the shape of a half-hemisphere, with three 150-watt tungsten halogen lamps which operate at 24 volts. The low voltage is required to prevent arcing from the lamp at the pressure used for deposition. The substrate may be heated directly or, for smaller samples, may be placed on a molybdenum disc which is heated radiantly by the lamps. The substrate heater is shown in Figure 3.

In anticipation of forming thin films of CdS on InP to form p-InP/n-CdS heterojunctions for investigation, and to act as a low-cost substrate for deposition of the InP, a vacuum system has been tooled up for deposition of CdS films. This is an oil-pumped system with a single source made out of graphite, similar to the deposition systems used in formation of the CdS film for the CdS/Cu_2S solar cell. Films of CdS about 30μ thick were produced. When processed into Cu_2S/CdS solar cells

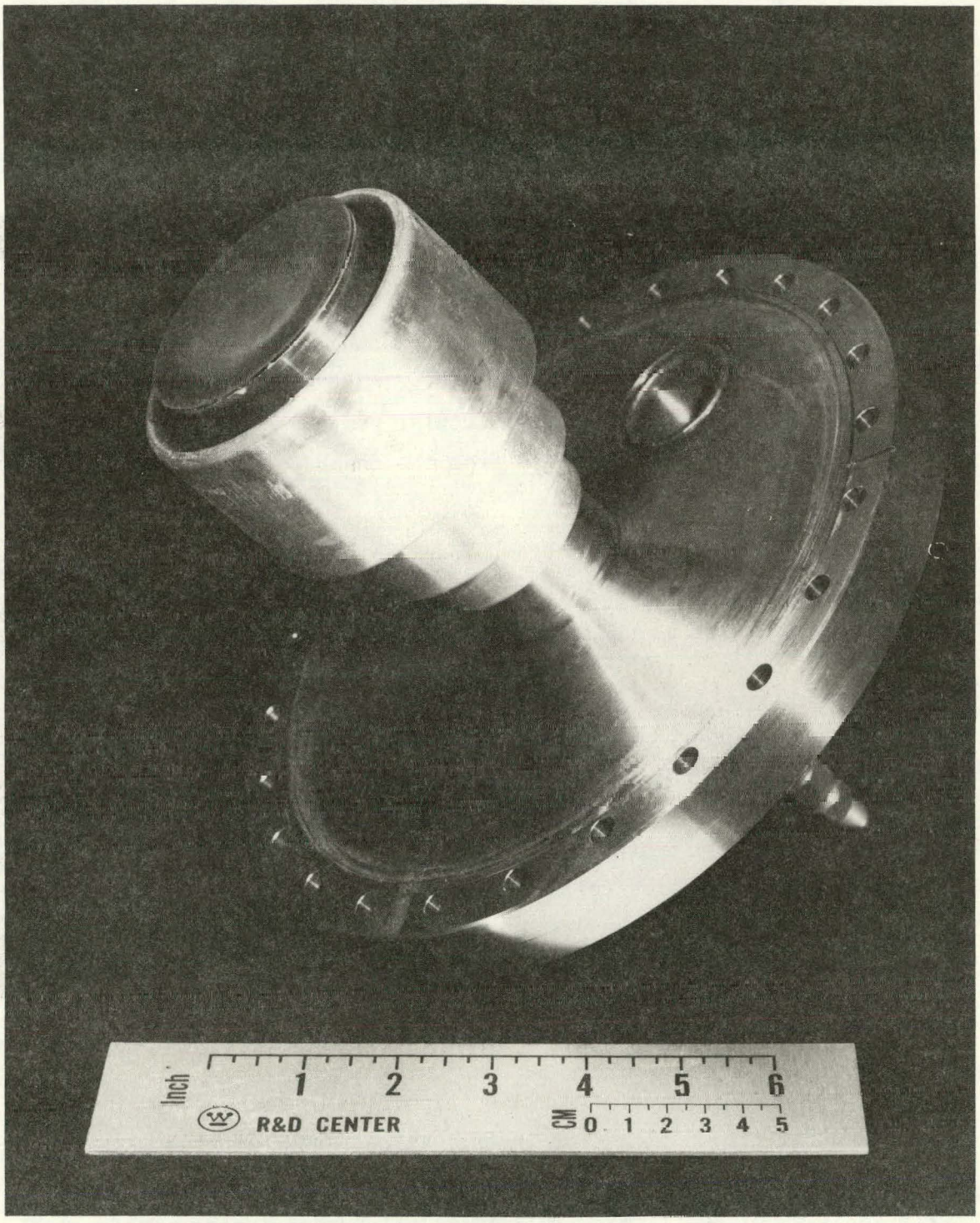

Fig. 2. Water cooled RF sputtering target holder for UHV system.

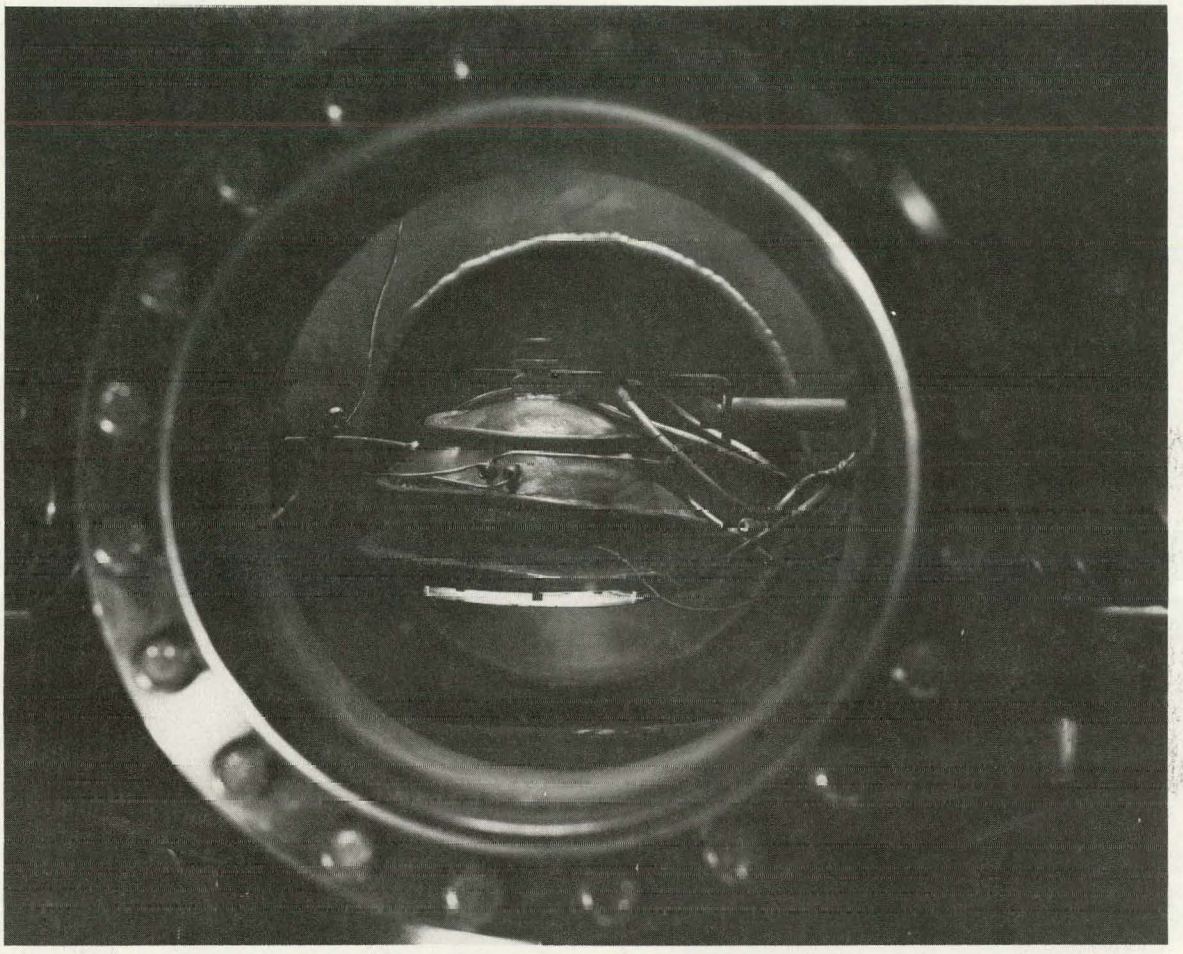

Fig. 3. Water cooled substrate heater. Substrate rests on three stand-off on top of heater and is radiantly heated by three 150 watts, 24 volts lamps.

the films gave performance nearly comparable to that of CdS films deposited in a standard system used in earlier solar cell programs. Erratic deposition rate monitor behavior developed in the new system. Steps will be taken to correct this problem.

2.2 Film Characterization

No depositions of InP have been made in the system as yet. However, some single crystals of InP have been plasma etched using $SiCl_4$ as the etching gas. An etching rate of 60 Å/min was obtained using 100% $SiCl_4$ and a power input of 50 watts. For these conditions, the etched surface was slightly textured after etching. Reducing the $SiCl_4$ concentration and/or lowering the power input would be expected to produce a smoother etch at a sacrifice in the etching rate. Assuming the free chlorine is responsible for the etching effect, hydrogen chloride should be a better choice. This will be tried in future work.

3. FUTURE PLANS

The immediate goal is the deposition of thin films of InP. The initial approach will be to use TEI connected directly to the vacuum system. These films will be evaluated by Auger and/or ESCA to determine the composition. In addition, the chamber pressure and/or power input to the sputtering unit will be varied, which will produce some amount of sputtered indium in the growing film to determine this effect on the deposited film. Studies will be made on the introduction of the In from $InCl_3$. This would require a heated source but should be a more pure source for the In.

Studies on the etching of InP by HCl and/or $SiCl_4$ will continue. A clean surface is very important for the growth of epitaxial layers, and this is a potential advantage of the plasma processing.