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AMORPHOUS BORON-SILICON-HYDROGEN ALLOYS FOR THIN-FILM HETEROJUNCTION SOLAR CELLS

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PREFACE

This Quarterly Report covers the work performed by the Display and Energy Systems Research Laboratory of RCA Laboratories, Princeton, New Jersey for the period 1 June 1980 to 31 August 1980 under Contract No. XS-0-9010-6. The Laboratory Director is Brown F Williams; D. E. Carlson is the Group Head and A. R. Moore is the Project Scientist.

The contract objectives are to deposit a-B:Si:H alloys in a dc proximity glow-discharge system, to characterize these films as a function of deposition conditions, to fabricate a-B:Si:H/a-Si:H heterojunction devices, and to characterize these devices.

SUMMARY

Amorphous boron-silicon-hydrogen (a-B:Si:H) films have been grown in dc proximity glow discharges in atmospheres containing B_2H_6, SiH_4 and H_2. The films are p-type and exhibit conductivities as high as $\sim 3\times10^{-4}\ \Omega^{-1}\ \mathrm{cm}^{-1}$. They do not exhibit any significant photoconductivity or photoluminescence. In the next quarter we plan to construct and characterize a-B:Si:H/a-Si:H heterojunction solar cells.

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SECTION 1.0

INTRODUCTION

Present amorphous silicon solar cells use undoped amorphous silicon (a-Si:H) base material. Phosphine (PH_3) and diborane (B_2H_6) are introduced in small amounts into the silane (SiH_4) discharge to form, respectively, n- and p-type contact regions during the deposition, thus completing the formation of the p-i-n structure. Typical open-circuit voltages of 750 to 850 mV are obtained at one-sun illumination. The present program is an attempt to substitute a heterojunction of an amorphous boron-siliconhydrogen alloy (a-B:Si:H) for the p-type a-Si:H. We hope by this means to increase the open-circuit voltage and to realize subsidiary benefits of the greater built-in potential which should also improve the short-circuit current and fill factor. Thus, an improved conversion efficiency might result from the use of an a-B:Si:H/a-Si:H heterojunction.

Amorphous boron-silicon-hydrogen alloys are distinguished from p-type a-Si:H by the amount of boron incorporated into the film during growth from the gas discharge. When the fraction of boron in the gaseous atmosphere (and in the resulting film) exceeds a few percent, the films take on the character of an amorphous B:Si:H alloy rather than that of doped a-Si:H [1]. Alloys prepared over the entire composition range are described in the pioneering paper of Tsai [1]. Our initial aim has been to repeat some of the experiments of Tsai using other methods of deposition. Tsai used rf plasma decomposition while in the present investigation both ac and dc proximity discharges are used; it is known that the discharge conditions have an important influence on the properties. After characterizing the grown films we will select the composition and discharge conditions which seem to offer the most promise as heterojunction contacts for solar cells.

SECTION 2.0

DEPOSITION CONDITIONS

Most of the a-B:Si:H films were grown in a dc proximity discharge mode with an applied voltage of 900 to 1000 V and a current density of 0.16 mA/cm^2 to the cathodic screen. The substrates were positioned ∿1.3 cm below the cathodic screen, and the anode screen was ∿1.3 cm above the cathode (see Fig. 2-1). The discharge atmosphere usually consisted of mixtures of SiH_4 and 15.4 vol% B_2H_6 in H_2. The pressure was ∿0.65 Torr and the flow rate 50 standard cm^3 per minute (sccm).

The films were deposited in a temperature gradient running from ∿250 to ∿400°C over 9 cm. The gradient heater consisted of a stainless-steel plate with a SiC glow bar located at one end of the plate. The glow bar was housed in a stainless-steel tube welded to the base plate, and a fused silica tube was used to electrically isolate the glow bar. As shown in Fig. 2-1, the entire base plate was contained in a stainless-steel reaction chamber with the gases admitted through a funnel at one end (the opposite end of the chamber was the exhaust port). A flow rate of 50 sccm is sufficient to prevent impurities from the heater or the outer bell jar walls from reaching the growing film. The reaction chamber was grounded, and the discharge electrodes were allowed to float; the anode was typically +80 V above ground.

Several substrates were used in each deposition run: a fused silica strip coated with Cr stripes (for conductivity measurements), two small fused silica plates (for optical absorption measurements) and two single-crystal silicon chips (for infrared absorption measurements). The fused silica strip was 10 cm long with Cr stripes ∿1.7 mm wide and ∿1.7 mm apart. The small fused silica plates and silicon chips were located near the hot and cold ends of the base plate. The deposition rate varied from ∿50 nm/min at the cold end to ∿15 nm/min at the hot end. This variation appears to be caused partly by a gas depletion effect since the gas flows over the substrate from the cold to hot ends.

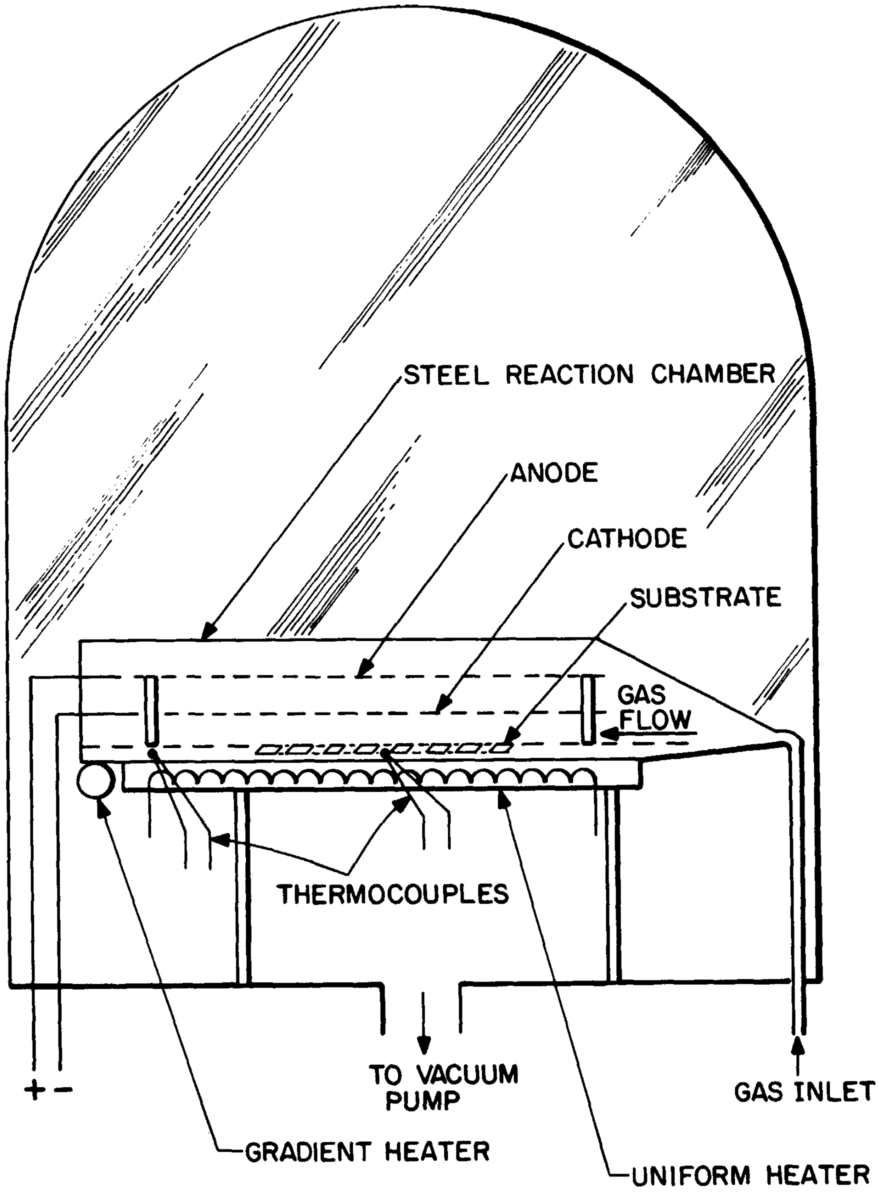

Figure 2-1. A DIAGRAM OF THE dc PROXIMITY GLOW-DISCHARGE DISPOSITION SYSTEM

SECTION 3.0

EXPERIMENTAL RESULTS

The conductivity was measured in the dark by means of the four-probe technique. Figure 3-1 shows the conductivity obtained in typical gradient runs in which the boron concentation in the gas, $X_g = [B_2H_6]/([B_2H_6] + [SiH_4])$, ran from 0.5 to 0.95. The trend is that higher substrate temperatures and lower boron concentrations result in higher room-temperature conductivity. No measurements were made on samples of boron concentration lower than 50% because Tsai's results [1] showed that the situation reverses below this value, yielding lower conductivity. All samples were p-type by thermoelectric power test.

The conductivity was measured as a function of temperature for a number of representative samples. The logarithmic plots vs reciprocal temperature do not give straight lines over a very large temperature range, as was also found by Tsai [1]. The high temperature end near 500 K appears to be most representative of the activation energy for conduction in the extended states. In this range an activation energy of 0.32 eV was found for $X_g = 0.5$ and substrate temperature at 380°C, and over 0.4 eV for $X_g = 0.8$. Since these values appear fairly high, we have begun annealing studies. Preliminary results indicate that annealing increases the conductivity of the films deposited at lower substrate temperatures, while not having as much effect on higher T_s samples. These experiments are in progress.

These a-B:Si:H films do not exhibit any significant photoconductivity or photoluminescence. (Persans et al. [2] also reported the absence of photoconductivity.) These results are not surprising in view of the large electron spin densities ($\sim 10^{18}$ to 10^{19} cm^{-3}) reported by Tsai [1].

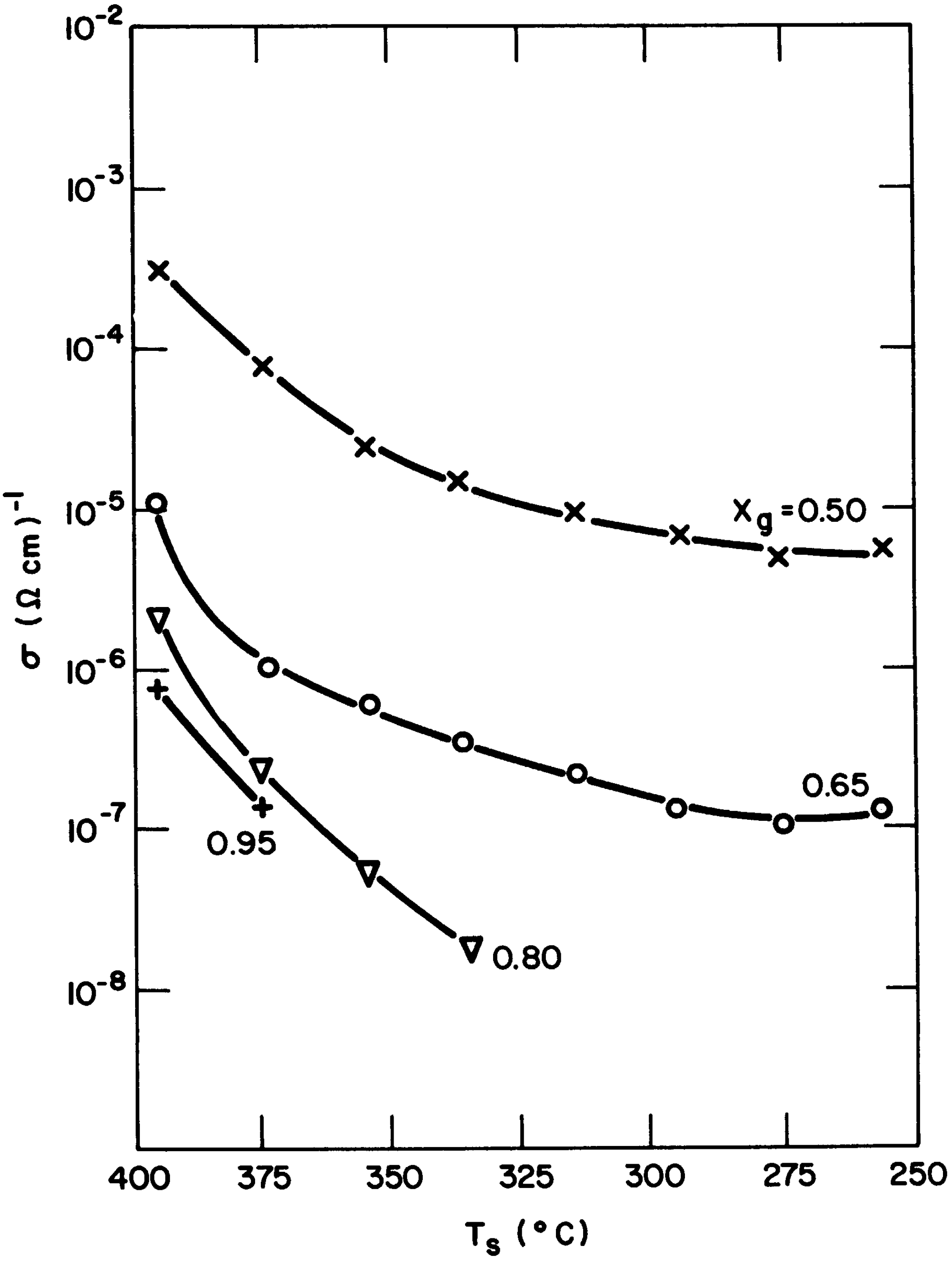

Figure 3-1. CONDUCTIVITY AS A FUNCTION OF SUBSTRATE TEMPERATURE FOR A SERIES OF a-B:Si:H FILMS. $X_g = [B_2H_6]/([B_2H_6] + [SiH_4])$

SECTION 4.0

CONCLUSIONS

Our preliminary studies show that the a-B:Si:H films produced from a dc proximity glow discharge are p-type and relatively conductive. We also have evidence that the defect density is relatively high since the films do not exhibit significant photoconductivity or photoluminescence.

In the next quarter we will start construction and characterization of a-B:Si:H/a-Si:H heterojunction cells. As long as the solar cell is built so that light is incident on the p-layer, a large band gap (optical window) is needed for the heterojunction material. However, recent cells have been most successful with the p-layer buried next to the steel substrate. If the a-B:Si:H alloy substitutes for this p-layer, the band gap is of lesser importance. Yet to get larger V_{oc} the Fermi level should be as close as possible to the valence band; hence the importance of the activation energy measurements. In the next quarter we will extend these measurements and include optical data. It appears that a choice of X_g somewhat lower than initially anticipated will be possible for buried p-layer cells. Also, annealing will be simplified with buried p-layer, since high-temperature treatment will not influence the subsequent i-layer deposition.

REFERENCES

1. C. C. Tsai, Phys. Rev. B19, 2034 (1979).
2. P. D. Persans, C. C. Tsai, and H. Fritzsche, Bull. Am. Phys. Soc. 23, 310 (1978).

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