HIGH EFFICIENCY SOLAR CELL PANEL

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Off Campus Project

by

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ABSTRACT

Solar Cells of at least 10% conversion efficiency were fabricated from silicon wafers of one inch diameter and the same processing procedure was applied to wafers of three inch diameter. Four of the three inch diameter solar cells were affixed to a galvanized steel plate and hooked in a parallel configuration to make a solar cell panel. A piece of special plastic was placed over the solar cells on the panel and hermetically sealed to protect the solar cells from the environment which in time would degrade the performance of the solar cells.

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INTRODUCTION

In order to provide electrical energy for a house a generator has to be constructed from a large number of solar cells. By mounting the solar cells onto panels the job of assembling the generator is made easier. The power output of the generator is determined by the number of panels comprising the generator and the voltage is determined by the way the panels are interconnected. To allow a heat collecting system to be operated in conjunction with the generator the panels have to be good thermal conductors. A typical heat collector would be air flowing beneath the panels. The galvanized steel plate to which the solar cells are mounted allows high conduction of heat from the front of the panel where it is absorbed to the back of the panel where it can be collected. The panel has to be covered with something to prevent the heat from escaping from the front of the panel. A piece of highly transparent plastic with a dead airspace between it and the galvanized steel plate prevents heat from escaping from the front surface of the panel. The plastic has to be highly transparent so that the conversion efficiency of the solar cells isn't severely lowered and it has to be durable enough that it doesn't decompose. This plastic cover is hermetically sealed to the galvanized steel plate to prevent water and air from reaching the solar cells.

The basic processing steps used in preparing the solar cells were the same as were used in my first project.[1] To increase the conversion efficiency of the bare solar cells the reflection of light from the active surface had to be reduced. A suitable antireflection film had to be found to apply onto the surface to reduce the reflection of light. Some means of fastening the solar cells to the galvanized steel plate had to be found. The panel has to operate over a large range of temperatures so the metalization on the wafer and the joint between this metalization and the galvanized steel plate have to be choosen so that the wafer or joint won't break under stresses due to differences in thermal expansions.

REDUCTION OF REFLECTION OF THE WAFER SURFACE

Texturizing[2] the silicon surface can substantially reduce the reflection of the surface. The simplest method to texturize the surface is to use a preferential etch on the silicon wafer. A boiling solution of 60% hydrazine hydrate in water preferentially etches (100) planes of silicon crystals. A (100) orientated wafer when etched by this solution exposes pyramids bonded by (111) planes on the wafer surface. Light falling normal to the wafer surface partially reflects from the walls of these pyramids and onto the wall of an adjacent pyramid. Since most of the incident light has at least two opportunities to be absorbed, the net reflection of the wafer will be lower than the reflection of a polished wafer surface from which light can reflect only once.

Wafers were etched for ten minutes in a boiling solution of 60% hydrazine hydrate and water. The surface of a (100) orientated wafer became texturized. This texturized wafer was then processed in the same way as reported in my previous project report. Prior to annealing the contacts the solar cells exhibited an increased short circuit current but there was a large contact resistance. If these solar cells were annealed to reduce the contact resistance they became shorted, indicating that the junction was not diffused uniformly into the wafer. This could be rationalized by noting that the pyramids on the texturized surface are about 15 microns in height and the doping film spun on the wafer are a few thousand angstroms thick. Since the pyramids are of the order of 100 times higher than the thickness of the doping film, the film formed by spining can't uniformly coat the entire surface of these pyramids. Diffusion from such a nonuniform film would lead to nonuniform doping. It was decided therefore that diffusion from spin on films was not compatible with this texturized surface. This texturization of the wafer was then not included as part of the processing steps.

It was decided next to try and deposit a film on the wafer surface by evaporation in a vacuum coater. It is reported[3] that Tantallum pentoxide Ta_2O_5 is a very good material to use as an antireflection coating for solar cells with very shallow junction depths. The shallow junction depth enhances the response of the solar cell to blue and ultra violet light. The antireflection coating has to be highly transparent to the blue and ultraviolet light in order to gain the full benefit of the very shallow junction depth. When Ta_2O_5 is properly deposited on the solar cell it is the most transparent of the materials which have been used as antireflection coatings on silicon. To minimize the reflection, the optical thickness is made one quarter of a wavelength thick for light of a wavelength of 6000 Angstroms.

It was decided to try and deposit a film of Ta_2O_5 onto the solar cells as an antireflection coating. Ta_2O_5 was obtained in powder form and evaporation was attempted from a tantallum boat as is recommended.[4] The tantallum boat alloyed with the posts used for holding the boat and broke before the temperature was sufficient to melt the powdered Ta_2O_5. It was decided to try a tungstun boat rather than a tantallum boat. Tungstun has much better mechanical properties at elevated temperatures and was found adequate to evaporate the Ta_2O_5 powder. The Ta_2O_5 decomposes when it is heated, outgasing oxygen. It is recommended[4] that an atmosphere of oxygen at a pressure of 10^{-3} torr should be maintained in the vacuum coater during the evaporation to ensure that the deposited film is Ta_2O_5. Oxygen was introduced into the vacuum coater through a small leak and the pressure was adjusted by varying the size of the leak. The high pressure made it necessary to place the solar cell close to the boat during the evaporation in order to obtain a film of adequate thickness. This created two problems. The deposited film on the solar cell was not uniform and the quartz crystal thickness monitor was heated by the boat preventing an accurate determination of the film thickness. Rather than working further to obtain a suitable coating of Ta_2O_5 it was decided to look for some other suitable material which may not be as good as Ta_2O_5 but would be a lot easier to deposit.

Films of silicon dioxide SiO_2 have been used for antireflection coatings[5] on silicon solar cells. There are a variety of methods to obtain a SiO_2 film on silicon. The wafer could be thermally oxidized to the desired thickness or SiO_2 could be evaporated onto the surface. Rather than attempting these techniques it was decided to investigate the behavior of the SiO_2 film formed by spinning a solution which decomposes to SiO_2 onto the wafer.

The solution used for doping a wafer with phosphorus contains an organic compound which decomposes to SiO_2 when it is spun onto the wafer and dryed. The thickness of a film formed on a spinning wafer is determined by the viscosity of the fluid forming the film and the speed at which the wafer is rotated.[6] The required film thickness can therefore be obtained by adjusting the viscosity of the liquid and the speed of rotation. An old vial of this doping solution was diluted with methanal until a speed of about 2000 rpm produced a film of the desired thickness. These films were then put on solar cells to determine how much they would increase the conversion efficiency of a bare solar cell. Figure 1 is the characteristics of a bare solar cell of 2 cm radius under illumination of 100 mw/cm^2. The short circuit current density is 20.8 ma/cm^2 and the conversion efficiency is 8.8%. Figure 2 is the characteristics of the same solar cell with a film spun onto the surface. The short circuit current density is 27.5 ma/cm^2 and the efficiency is 11.8%. The increase in short circuit current density is 32% and the increase in efficiency is 33%. This indicated that this spin on film of SiO_2 substantially increases the efficiency of the bare solar cell. Assuming a 33% improvement, a bare solar cell of at least 7.5% conversion efficiency would produce a coated cell with a minimum of 10% efficiency. It was therefore concluded that the spun on film of SiO_2 would be adequate for the production of 10% efficient solar cells.

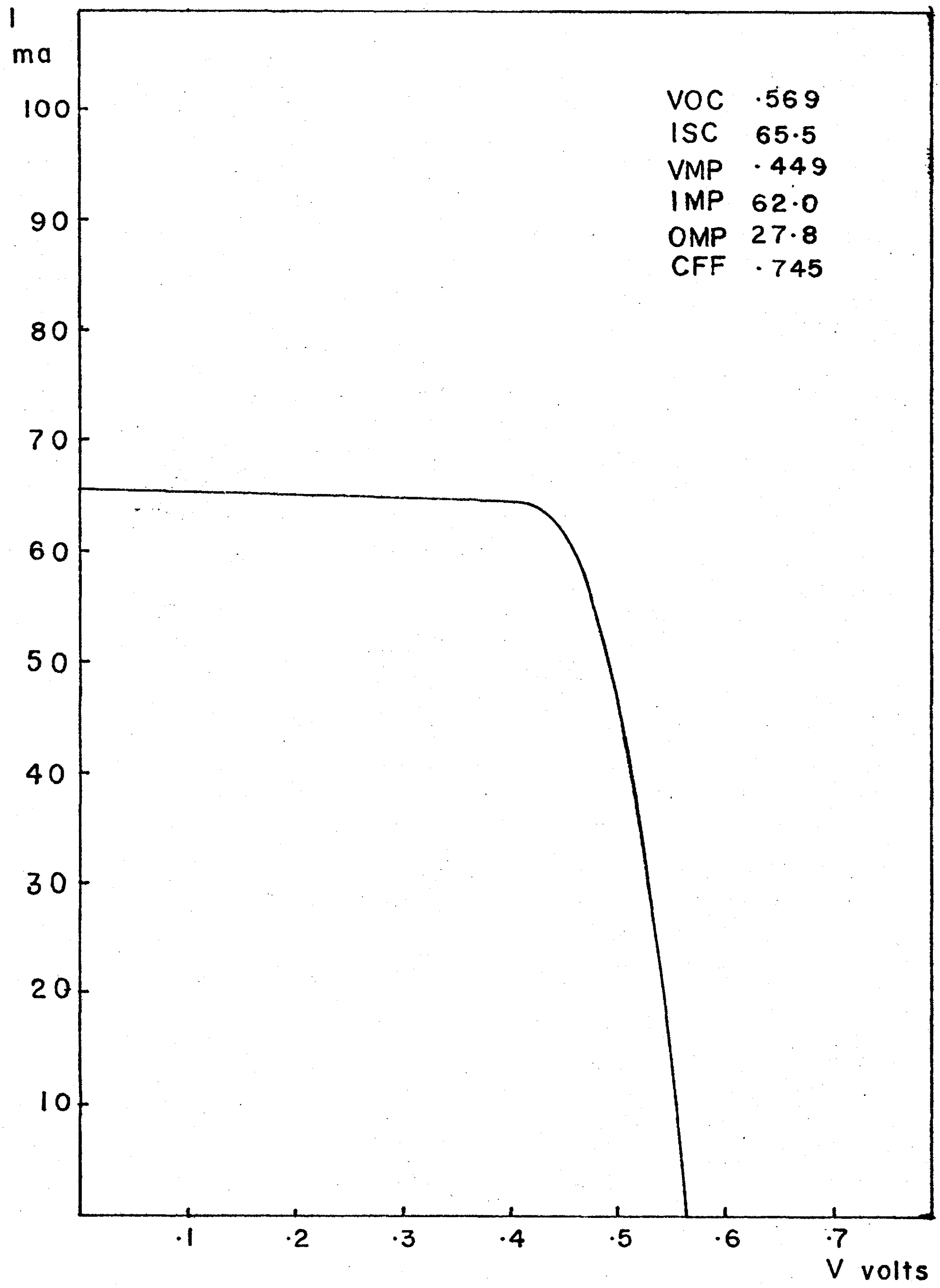

Figure I Solar Cell without SiO_2 Film

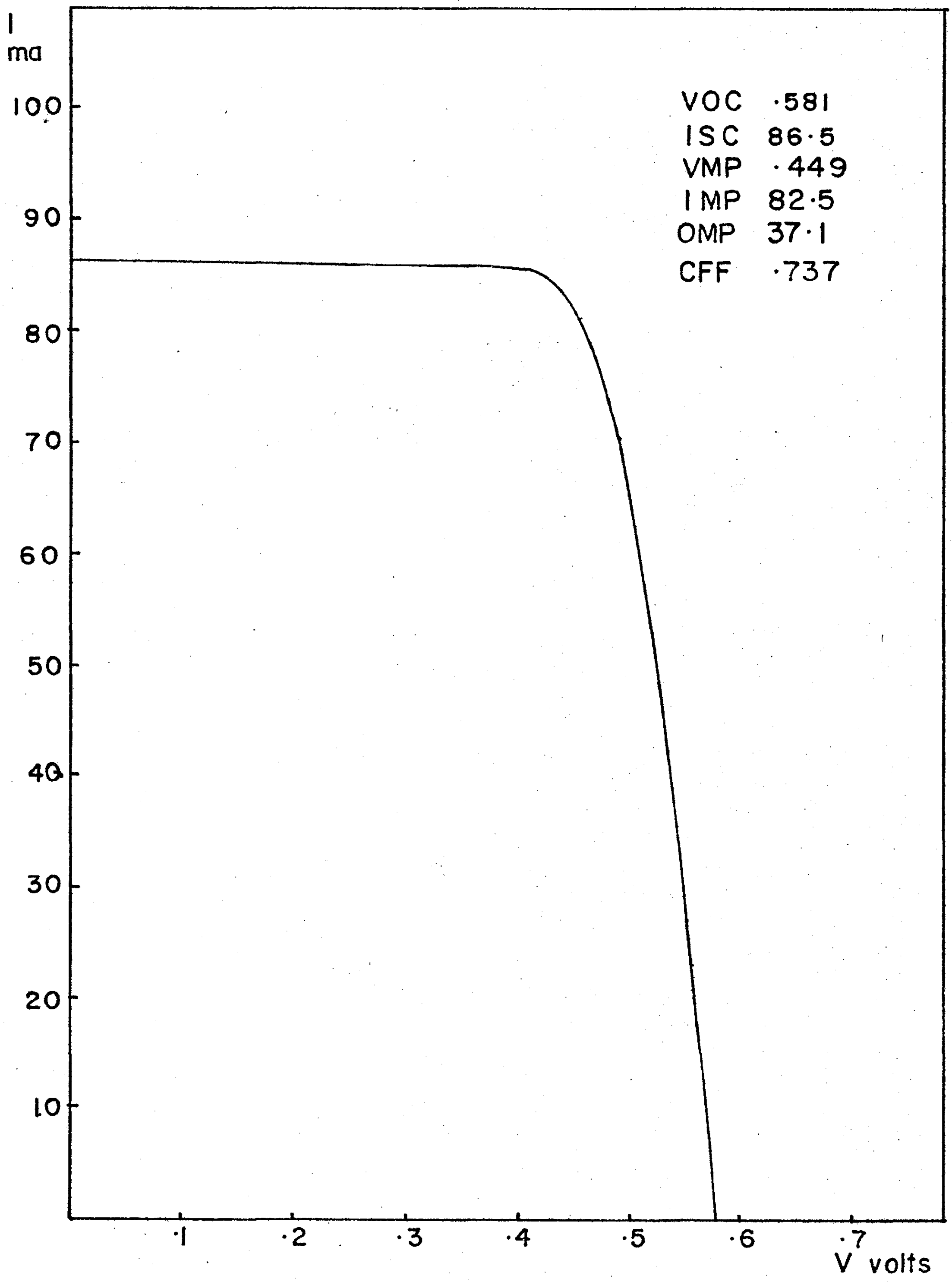

Figure 2 Solar Cell with SiO_2 Film

METALIZATION

In order to fasten the solar cells to the galvanized steel plate the metalization has to be wettable by some solder which would also wet the galvanized steel. The metalization also has to make a good electrical connection and has to adhere well to the silicon. The metalization has to be choosen so that there will be little problems with corrosion. Aluminum adheres well and makes a low resistance connection to the silicon. Aluminum is difficult to solder or electroplate with an easily solderable metal due to the thin tenacious oxide which forms rapidly when aluminum is exposed to air. Aluminum in contact with most metals would be very prone to corrosion. A metalization other than aluminum is necessary if the solar cells are to be soldered to the galvanized steel plate. Nickle is reported[7] to adhere moderately well and make a good electrical connection to silicon. It was decided to try electroless nickle plating. If there is too much phosphorus present in the electroless nickle deposit it is not solderable.[8] To overcome this problem it was decided to electroplate copper onto the electroless nickle.

Neckel was plated from an alkaline bath of the following composition.[9]

Nickel chloride	30 gm/litre
Sodium hypophosphite	10 gm/litre
Ammonium citrate	65 gm/litre
Ammonium chloride	50 gm/litre

Ammonium hydroxide was added to the solution until it turned from green to blue in colour. The solution was maintained at 100° C during the plating. Nickle was easily deposited onto the silicon wafer however the film was easily peeled from the wafer. Under the nickle film on the n surface of the wafer there was a film of black material. The composition of this film was unknown and it was very difficult to etch off. This film possibly caused the poor adhesion of the nickle film to the wafer and may lead to high contact resistance and contamination of the wafer. Rather than proceeding to discover the cause of the black film it was decided to try an acid electroless nickle plating bath. The composition of this acid bath is as follows.[10]

Nickle sulphate	29 gm/ litre
Sodium hypophosphite	17 gm/ litre
Sodium succinate	15 gm/ litre
Succinic acid	1.3 gm/ litre

The bath was used at room temperature. Prior to placing the wafer into the plating bath the wafer was sensitized in a dilute $SnCl_2$-HCl solution followed by a rinse in distilled water and then dipping in a dilute $pdCl_2$-HCl solution followed by a rinse in distilled water. The electroless nickle deposited adhered better, however the film would not coat the entire surface of the wafer. This could have been caused by slight nonuniformity in the doping or impurities on the wafer surface. Rather than spending more time to develop a technique to deposit a uniform adherent electroless nickle film, it was decided to look for another solution to the problem of mounting the solar cells onto the galvanized steel panel.

A technique used in micro electronics to bond chips is with an electrically conductive epoxy.[11] The epoxy is made conductive by filling it with a large percentage of small gold or silver particles. It was unknown how sucessfully this epoxy could be used to bond a three inch diameter wafer to a galvanized steel plate and how well it could tollerate the temperature range it would have to operate under. A small amount of this conductive epoxy[12] was obtained to evaluate it. Aluminum was used as the contact material to the silicon wafer in this evaluation. Wafers where cemented to pieces of galvanized steel and the epoxy was cured as recommended by the manufacturer. The resistance between the galvanized steel and aluminum was very low. To evaluate how well the epoxy joint could withstand the range of temperatures it would have to operate under, it was put into a furnace which could be cooled to liquid nitrogen temperature or heated to 300° C. With the cemented down wafer in the furnace, the temperature was set to -40°C. The furnace required about 10 minutes to reach the set point. The rate of cooling was much more rapid than would ever be encountered in nature. The wafer was left at this temperature for two hours and then it was removed to examine the epoxy joint. The wafer didn't break or the bond didn't break between the galvanized steel piece or the aluminum contact. There were a few small cracks in the epoxy. The wafer was placed back into the furnace and the temperature was set to 150°C and left for two hours. When the wafer was removed the epoxy was slightly soft but was viscous enough to hold the wafer in place. The cracks formed at the low temperature had annealed out. When the panel cooled to room temperature the electrical properties of the epoxy and the bond appeared to be as good as they were originally. If this panel was subjected to temperature like -100°C the wafer would break into pieces; however, the bond between the epoxy and metals was still intact. At high temperatures like 200°C the epoxy would burn in the air and the bond strength would be lowered. It would therefore appear that the epoxy should do a satisfactory job of bonding the solar cells to the galvanized steel plate for temperatures of operation between -40°C and 150°C. It was decided then to use aluminum contacts on the solar cells and conductive epoxy bonding to the galvanized steel plate for making a panel.

PACKAGING

The plastic cover has to be durable enough to withstand the humidity, air and high temperatures that would be encountered under exposure to the environment and sunlight. It has to be transparent enough to allow most of the sunlight through to the solar cells. A plastic which can be exposed to temperatures of 140°C on a continuous basis, has high strength, has high corrosion resistance and is highly transparent is a polycarbonate plastic. This polycarbonate plastic is marketed in North America by the General Electric Company under the trade name Lexan. A piece of Lexan large enough to cover the panel and one quarter inch thick was obtained. A hermetic seal was obtained between the galvanized steel plate and the lexan sheet with a gasket fitting around the edge of the panel, cut from a sheet of neoprene one quarter inch thick. To fasten the lexan to the galvanized steel plate holes were drilled through the lexan and galvanized steel plate around the edge. The holes in the galvanized steel plate were tapped so that screws could be used to hold the lexan tightly to the galvanized steel plate, making an airtight seal. Screws were used to hold the assembly together so that it could be easily disassembled in the future to examine the solar cells.

Figure 3 is the test results of a panel of four, three inch diameter solar cells without the lexan cover. The panel was tested under sunlight of intensity 86.5 mw/cm^2 measured with a pyranometer. The active area of each solar cell was about 38 cm^2 giving an efficiency of 5.1%. Figure 4 is the test results of the same panel with the lexan cover in place. The intensity of the sunlight measured with the pyranometer was 92.7 mw/cm^2. The efficiency of the solar cells was 4.3%. Assuming the decrease in efficiency was entirely due to the lexan cover, it caused a 15.7% drop in the efficiency. The cover could be made much thinner to avoid the large drop in efficiency. The thick cover here was used for mechanical strength. The lexan should be a satisfactory cover for the panel in a thickness much thinner than one quarter of an inch.

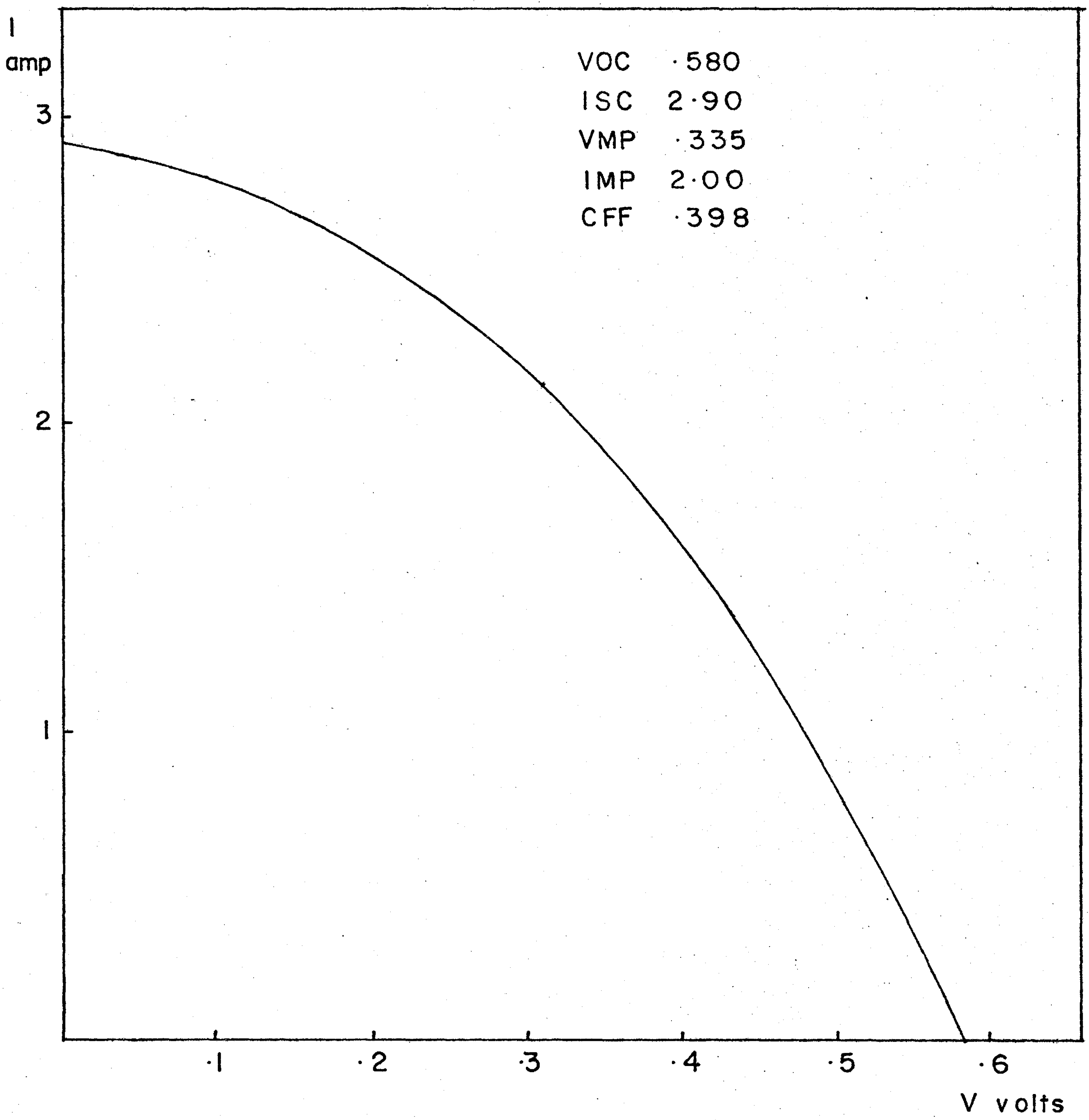

Figure 3 Panel without Cover

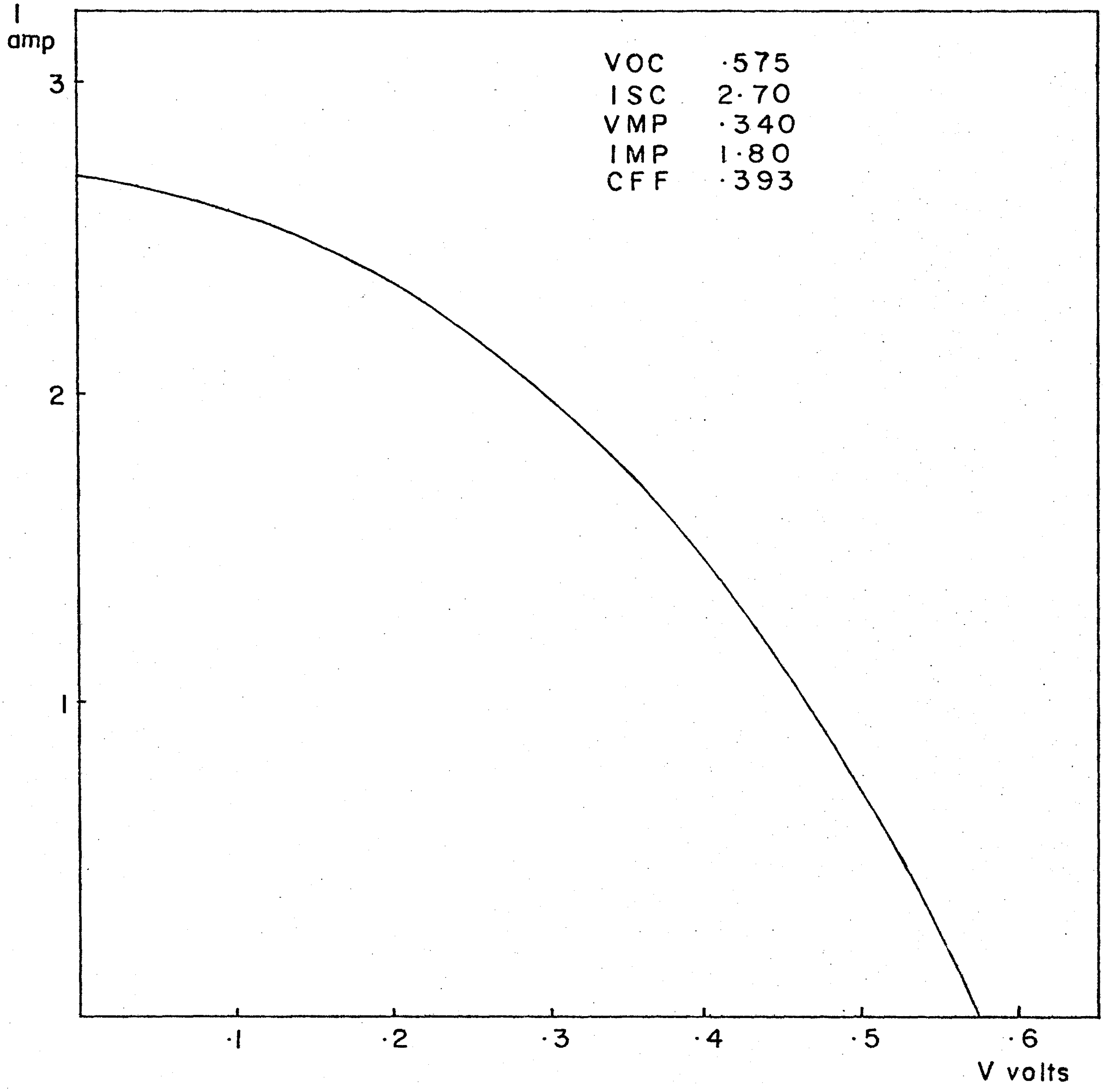

Figure 4 Panel with Cover

WORK ON THREE INCH DIAMETER WAFERS

The same processing steps were used for the three inch diameter wafers as were used for the one inch diameter wafers. A larger beaker had to be used to clean the wafers, more doping solution had to be applied to the wafer to completely coat the surface and a larger furnace had to be used to do the diffusion. The large size of the three inch diameter wafers made them more susceptable to accidental breakage so more care had to be excercised in handling them. A front grid pattern similar to the one used on the one inch diameter solar cell with fifteen fingers was used on the three inch diameter solar cells. There wasn't a furnace convenient which could be used to anneal the contacts so the solar cells were placed on a hot plate for 10 minutes which adequately reduced the contact resistance.

Figure 5 through 8 are test results for four solar cells which were mounted onto a panel. The aluminum metalization on the front of the solar cells was too thin to efficiently collect the current from the entire wafer surface. The voltage drops along the grid fingers were so large that the curve fill factors were very low. To partially avoid this, during the testing the probe for collecting current and the probe for measuring the voltage were placed at opposite ends of the bar connecting the fingers of the grid.

The illumination intensity for the tests was 100 mw/cm^2. The active area of each solar cell was about 38 cm^2. The short circuit current densities vary from 25 ma/cm^2 to 26.8 ma/cm^2 and the efficiencies vary from 7.1% to 8.75%. The curve fill factors are relatively low for all of the solar cells due to the front collecting grid. With curve fill factors of .7 or greater all of these solar cells would have efficiencies in excess of 10%. With a lower resistance front grid it should be easy to obtain a curve fill factor in excess of .7. It would then appear that the processing steps developed for the one inch diameter wafers work equally well for wafers of three inch diameter.

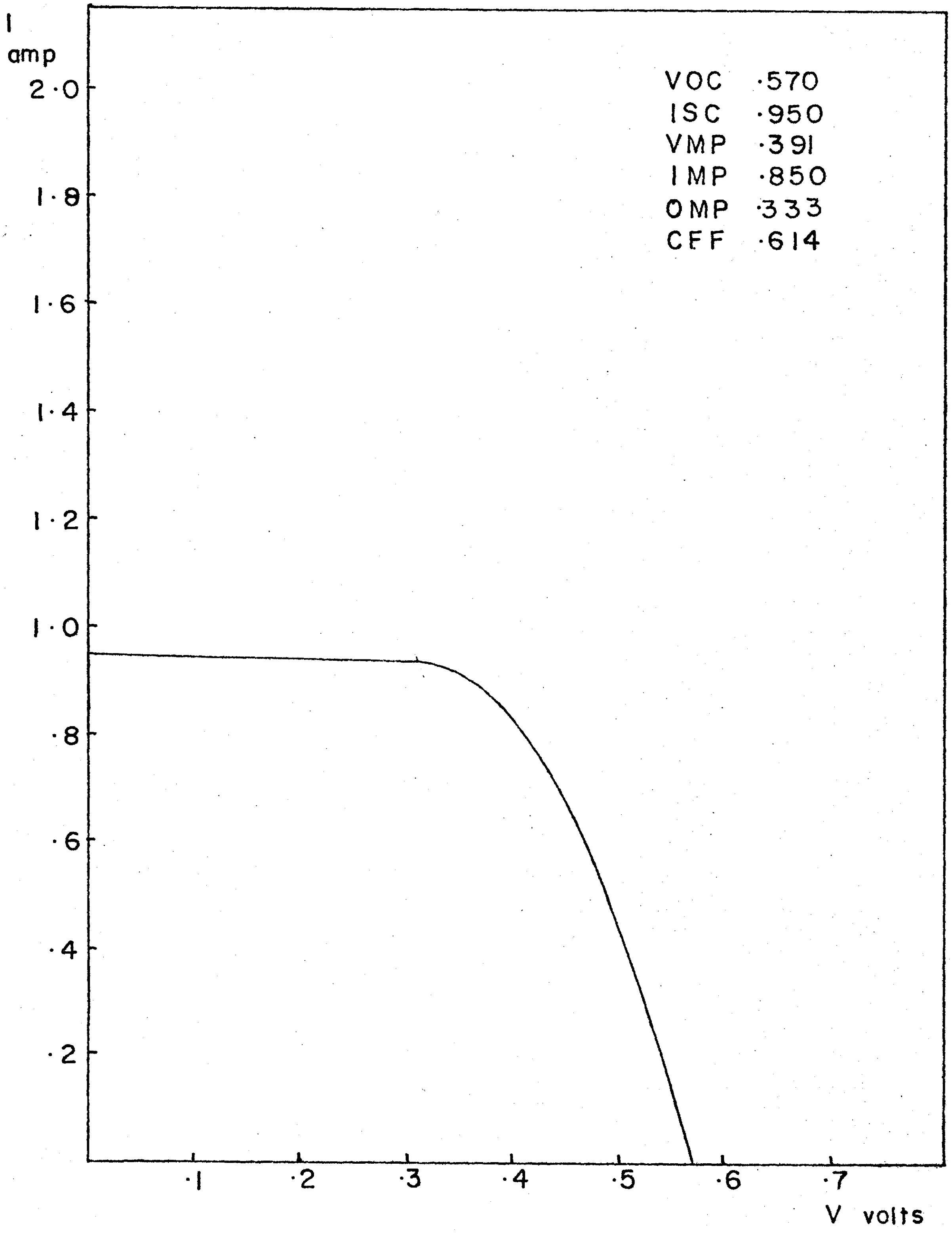

Figure 5 Three inch diameter Solar Cell

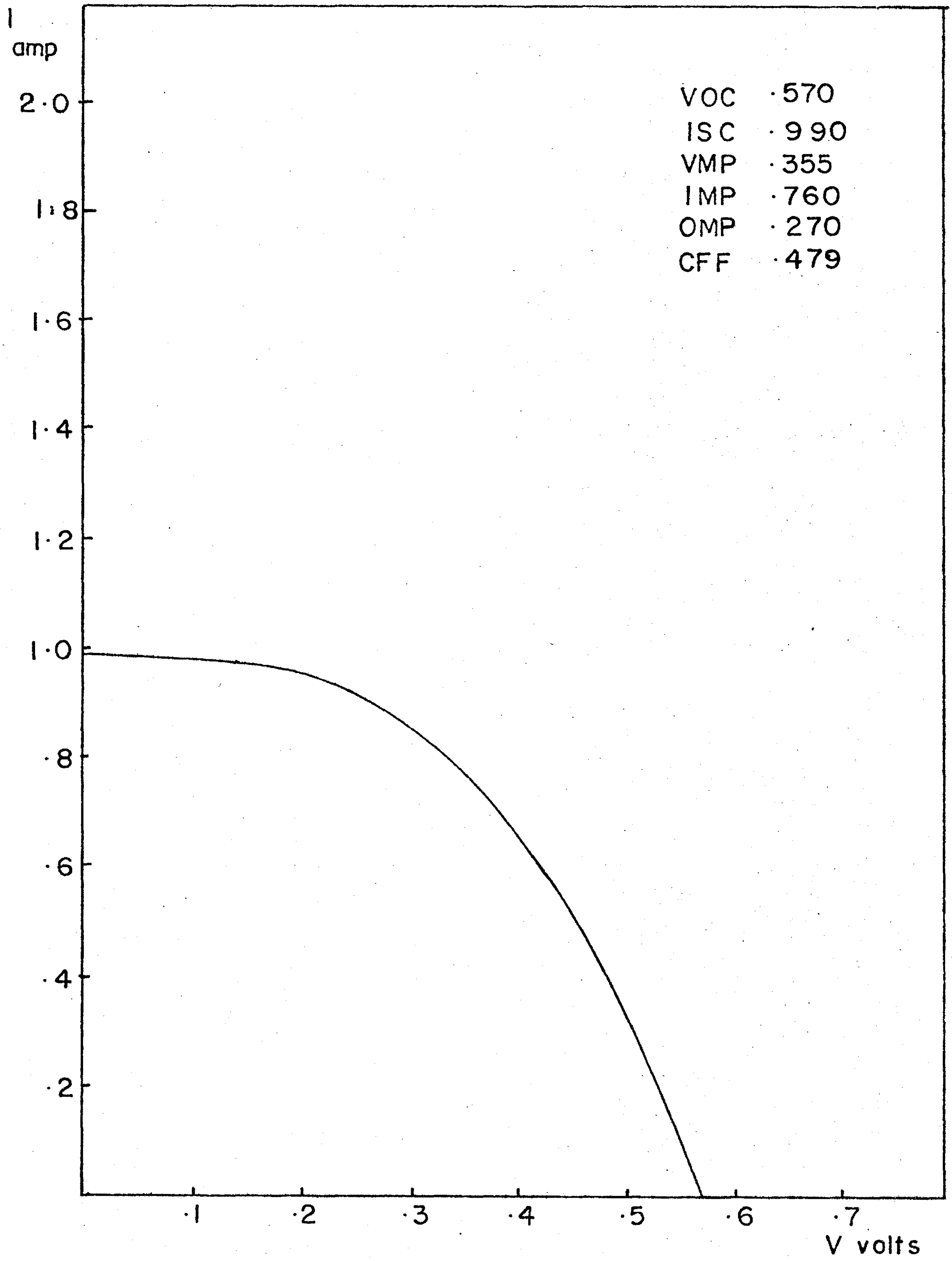

Figure 6 Three inch diameter Solar Cell

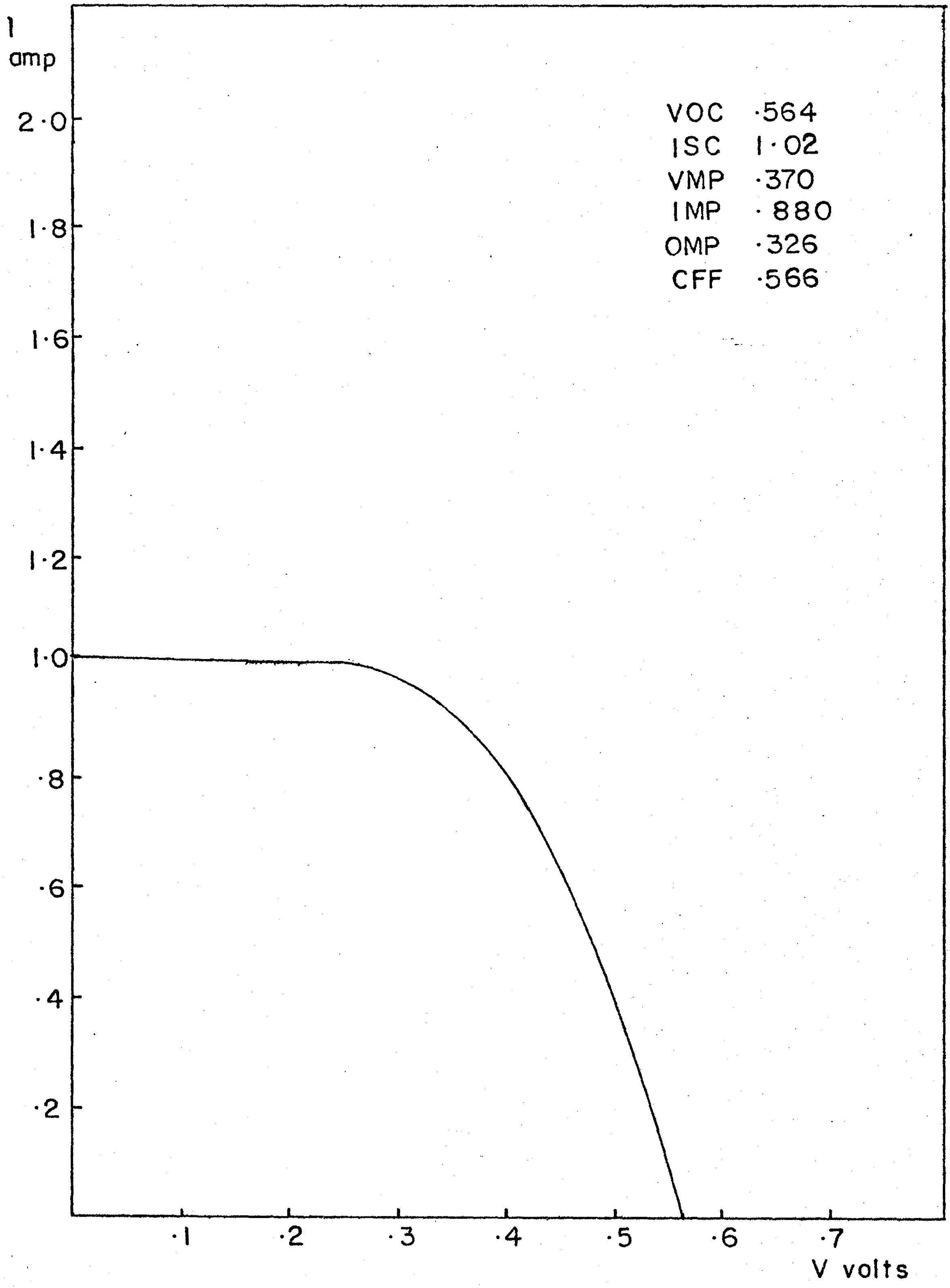

Figure 7 Three inch diameter Solar Cell

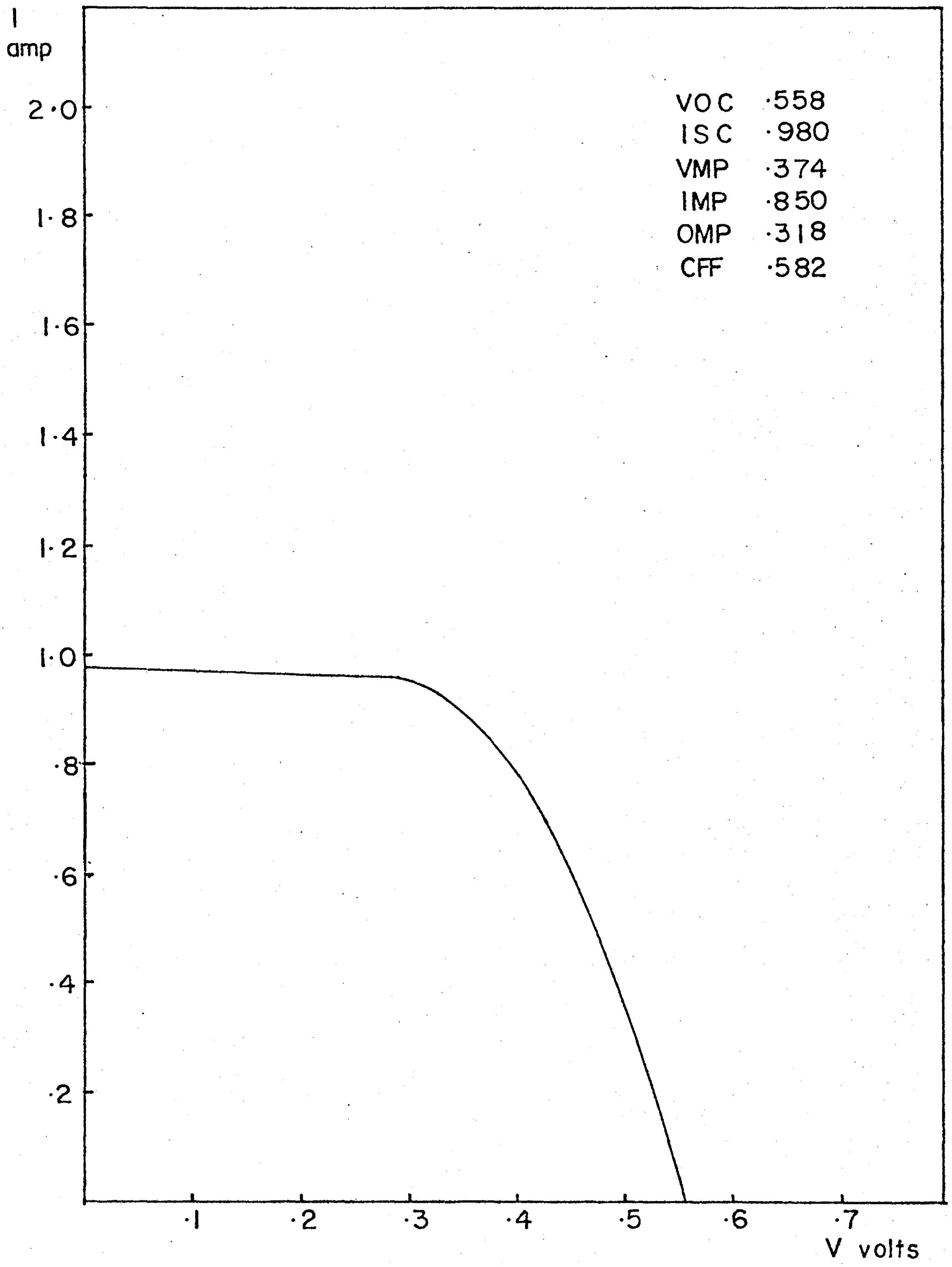

Figure 8 Three inch diameter Solar Cell

CONCLUSIONS

With the application of an antireflection coating, the efficiencies of the solar cells produced according to the procedure given in my first project report were increased beyond the 10% objective. A more efficient antireflection coating would increase the efficiency of the solar cells even further. More work should be put into developing a procedure for depositing a suitable ta_2O_5 antireflection coating.

The conductive epoxy appears to be a suitable means of fastening the solar cells to the galvanized steel panel. The panel should be subjected to more environmental testing to determine how well and how long the epoxy can withstand the conditions under which it has to operate. A thinner sheet of Lexan should be used as a cover for the panel and a more efficient method should be investigated to obtain a hermetic seal.

The procedure developed for processing the one inch diameter wafers appears to work as well for processing three inch diameter wafers. The aluminum grid deposited on the front of the wafer was not adequate for the production of a three inch diameter solar cell with an efficiency in excess of 10%. This inadequacy could be rectified by developing a procedure to deposit a thicker film of aluminum or by developing a procedure to apply a film over the thin aluminum; for example, silk screening, a film of conductive epoxy over the aluminium.

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