THE HEWAC PILOT LINE EXPERIENCE

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INTRODUCTION

High Efficiency Wraparound Contact Solar Cells (HEWACS) are advanced silicon solar cells with both electrical contacts on the back side of the cell. Figure 1 shows a sketch of this device, which utilizes a screen-printed dielectric insulation layer to isolate the "N" and "P" contacts from each other. The NASA-Lewis Research Center is supporting the development work of this cell under Contract NAS3-21270 (and previously on NAS3-20065). The specific goals of this program are to develop a device exhibiting high AMO conversion efficiencies, and to mature and formalize the processing of such cells to a point where cell fabrication can be carried out by production personnel under operating production line conditions. Pilot production will then manufacture and deliver 1000 acceptable cells (minimum cell performance 13½%, minimum lot average 14%, AMO @ 25°C).

BACKGROUND

The flow chart in Figure 2 shows the baseline process sequence developed under NAS3-20065, and the process modifications made under the current program, NAS3-21270. The cells produced under NAS3-21270 measure 2 x 4 x 0.02 cm, feature a polished or planar front surface with dual AR coating, chromium-palladium-silver contact system and an aluminum back surface field in addition to the wraparound contacts and silica-seal dielectric insulator. A back surface reflector is not utilized. Material used is "P" type, boron doped, 7-14 ohm-cm, CZ silicon with (100) crystal orientation.

Laboratory experiments designed to optimize cell performance and cell processing have resulted in a device with high electrical performance. Some average performance data for these cells are as follows: Open-circuit voltage 620 mV, short-circuit current 340 mA, maximum power 159.8 mW, curve fill factor 0.752, efficiency (η) 14.8% and lot yielded approximately 65% (test data @ AMO, 25°C).

In addition to electrical tests, many screening tests have been performed on these devices. These include temperature cycling (100 cycles, -170°C to +75°C), tape peel tests, soldered tab pull tests and humidity testing. Although limited in nature, these tests do provide some idea as to the reliability of the cells. The devices tested were within contract requirements for all of the tests performed.

For more information about laboratory experiments, electrical performance, and screening tests, see "High Efficiency Wraparound Contact Solar Cells (HEWACS)", 14th IEEE Photovoltaic Specialists Conference - 1980 Proceedings.

Prior to the initiation of pilot production, a number of items had to be completed. First was the preparation of production-suitable software and quality control elements. The pilot line for this program is to be carried out by production personnel under operating production line conditions, therefore it is necessary to implement a complete software file. This means that an MCD (Manufacturing Control Document) had to be prepared, listing all of the process steps and Q.C. Inspection stages. Procedures had to be written and approved for each of the process steps and Engineering Line Instructions (ELI's) developed.

In addition, the need for a reconfigured back contact system was identified. An alternate back contact configuration is required for the HEWACS cell to make the device more suitable for some panel manufacturers' designs. Although the baseline wraparound design does simplify cell interconnecting compared to standard space cells, a back contact configuration utilizing the centerline of the cell for both N and P contacts would simplify cell interconnecting even further for some panel manufacturers. A sketch of the reconfigured contact that has been designed is shown in Figure 3.

RECONFIGURED BACK CONTACT

Approach

The approach used in the development of the reconfigured back contact HEWACS cell was as follows:

First the design and procurement of new tooling was necessary. This tooling included screens to be used in the dielectric print-on step, masks for the contact evaporation step, and a new electrical test fixture. Secondly, test lots were made and evaluated until a satisfactroy process was achieved. And finally, the pilot production software was revised to reflect the alternate back contact cell. It was decided to amend the program requirements for the contract and make the 1000 deliverable devices include 500 baseline type cells, and 500 alternate back contact cells. All electrical performance requirements and acceptance test requirements would be the same for both cell types.

Problems/Solutions

Problems, not common to those of the baseline cell design, were encountered and resolved with the reconfigured back contact. In the initial experiments, the same size (mesh) screens were used to print the dielectric insulation onto the ABC (alternate back contact) cells as were used on the baseline cells. This caused what proved to be the major stumbling block in the development of this cell type. By comparing the sketches of the two cell designs in Figures 1 and 3, it is obvious that the ABC cell (Figure 3) has much more of its back surface area covered with insulation material than does the baseline device. The additional insulation caused unacceptable bowing of the cells when the insulation layer was fired.

Several experiments were conducted employing different combinations of screen types and mesh sizes. Some cells were processed using a single layer of insulation, instead of the standard double-layer method used on the baseline cell. (Double-layer insulation minimizes the chances of pinholes which could lead to shunting of the cells.) Others were processed using double-layer insulation, but with finer mesh screens. The combination which was found to be acceptable from all aspects was the use of a fine mesh screen for the initial print-on step, followed by a standard mesh screen for the second print-on step. The single layer experiment failed because of shunting due to pinholes. The double-layer, fine mesh screen experiment failed because an inadequate amount of insulation was being applied to the wraparound edge of the cell, and the edges of the silicon were protruding from beneath the insulation layer, therefore causing shunting and poor cell performance.

Results

The flow chart in Figure 4 shows the process sequence used in the manufacturing of the baseline cell type. To the right, opposite its respective process step, are listed the changes required to make a HEWACS cell utilizing the alternate back contact. It is apparent that the ABC cell types can be made using the same process as the baseline cell, with a minimum of changes.

Electrical Performance

Since only a few process changes had to be made to produce the alternate back contact cell, it would seem logical that the electrical characteristics of the device would also remain very similar to the baseline cell type. This was found to be the case. Figure 5 shows a cell performance comparison of the baseline cell and the reconfigured contact cell. Note that both cell types in this comparison have only a single-layer antireflection coating, which explains the low short-circuit current (I_{sc}) and I_{mp} values. Also note that the reconfigured contact cells were tested at 28°C instead of 25°C. Therefore, they have lower open-circuit voltage (V_{oc}) and V_{mp} values than the baseline cell type. Otherwise, the two cell types are very similar to each other.

ADDITIONAL EXPERIMENTS

One of the contract requirements on the HEWACS device is that the cell utilizes a back surface reflector (BSR). However, during the development stages it was determined that a BSR would be impractical for this cell. First, the high temperature used to fire the dielectric insulation was too close to the aluminum-silicon eutectic temperature (577°C) and it was thought that the BSR on these cells would be rendered useless by the dielectric firing step. Secondly, through experimentation it was shown that in order to maximize adherence of the dielectric insulation to the back of the cell, the residual aluminum (post back surface field (BSF) formation) should remain on the device. It is standard procedure to use boiling HCl to remove the residual aluminum after BSF formation, and evaporate an aluminum BSR directly onto the aluminum-silicon regrowth layers. An advantage of leaving the residual aluminum on the back of the cell is that it acts as a back contact.

In order to further investigate the effects of residual aluminum on the device, additional experimentation was carried out under Spectrolab R&D. Conventional contact 2 x 2 cm cells with screen-printed back surface fields were fabricated with and without the residual aluminum left on the cell. Absorptance data are indicated below:

Cell Type	α
Residual Aluminum + Heat Treatment	.720
Residual Aluminum	.761
Evaporated BSR	.785

As can be seen, the cell group with the residual aluminum and the heat treatment had a significantly lower absorptance than the other cell types. Also of great interest was that this group had the highest value of open circuit voltage.

PILOT PRODUCTION

Start

With the completion of development of the reconfigured back contact cell, proofing of the evaporation tooling and finalization of the production software, the Pilot Line is at present under way. The material to be used has been grown, slabbed, and sliced into approximately 1150 wafers, 1.70" x 1.70" x 0.14" thick. (During processing, each wafer will be diced into two 2 x 4 cm cells, thereby providing for a maximum of 2300 cells.) These wafers were divided into 12 lots of 96 wafers each (one lot has only 94 wafers). Six of these lots will be used to make the baseline cells, and the other six lots for the alternate back contact type cell. All twelve lots went through the 30% NaOH etch, 3-1-2 polishing etch and phosphine diffusion. At this point a trial run was initiated before the actual pilot line. Two lots (one for each cell type) were run through the manufacturing process by production line personnel. This was done in an effort to determine what problems, if any, would be encountered by switching the process from the laboratory to the production line.

These two lots did run into some difficulty. Besides a few small problems which only required some minor adjustments to remedy, one large problem was ultimately responsible for the loss of both lots. Shortly before the start of the pilot production, OSHA banned the use of one of the solvents widely used at Spectrolab to clean cells. A substitute solvent was incorporated into the production process after it was found suitable for cleaning conventional cells. This new solvent simply replaced the old one in the already established cleaning sequence. Although this cleaning procedure with the new solvent worked satisfactorily on standard space cells, it failed on the HEWACS devices. The cleaning procedure and solvent used was not designed for cells that had a dielectric insulation layer screen printed onto the cell. The surfaces onto which the insulation layer was printed were not adequately prepared to allow for good adhesion between substrate and insulation. Therefore, when tape peel tests were run on these cells they exhibited excessive peeling of the dielectric insulation from the substrate.

New Cleaning Procedure

Experiments were then conducted in an attempt to develop a new solvent and/or cleaning procedure. Many combinations of solvents and procedures were tried. It was found that the most successful combination tried involved the use of the same solvent Production was using, but the cleaning procedure had to be changed. The software was then changed and the formal pilot line started.

Current Status

The pilot production is currently in progress. The ten lots of cells have been processed through the screen-printed aluminum back surface field (BSF) step and are now in the cell dice step. All ten lots should be completed by the end of October.

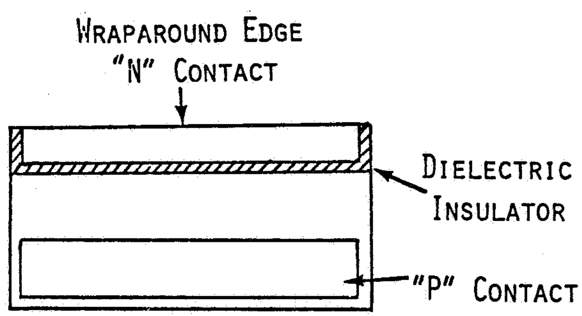

FIGURE 1

SKETCH SHOWING BACK CONTACT CONFIGURATION OF BASELINE HEWACS CELL

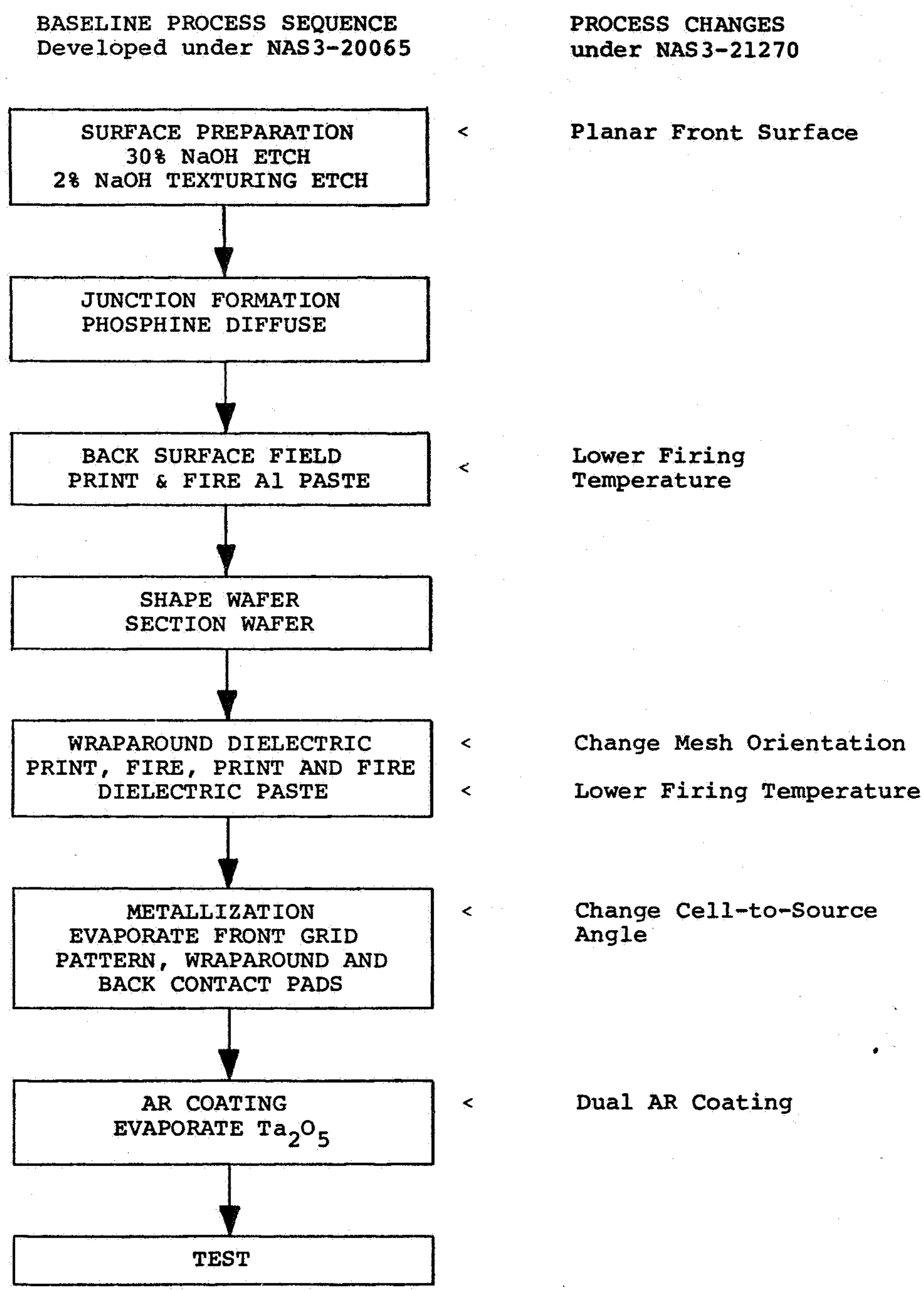

Figure 2. FLOW CHART SHOWING BACK CONTACT CONFIGURATION OF BASELINE HEWACS CELL

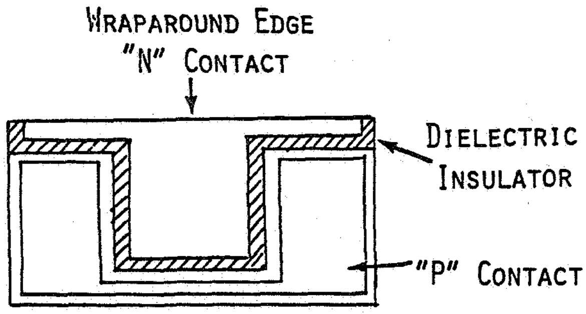

FIGURE 3

SKETCH SHOWING BACK CONTACT CONFIGURATION
OF ALTERNATE BACK CONTACT HEWACS CELL

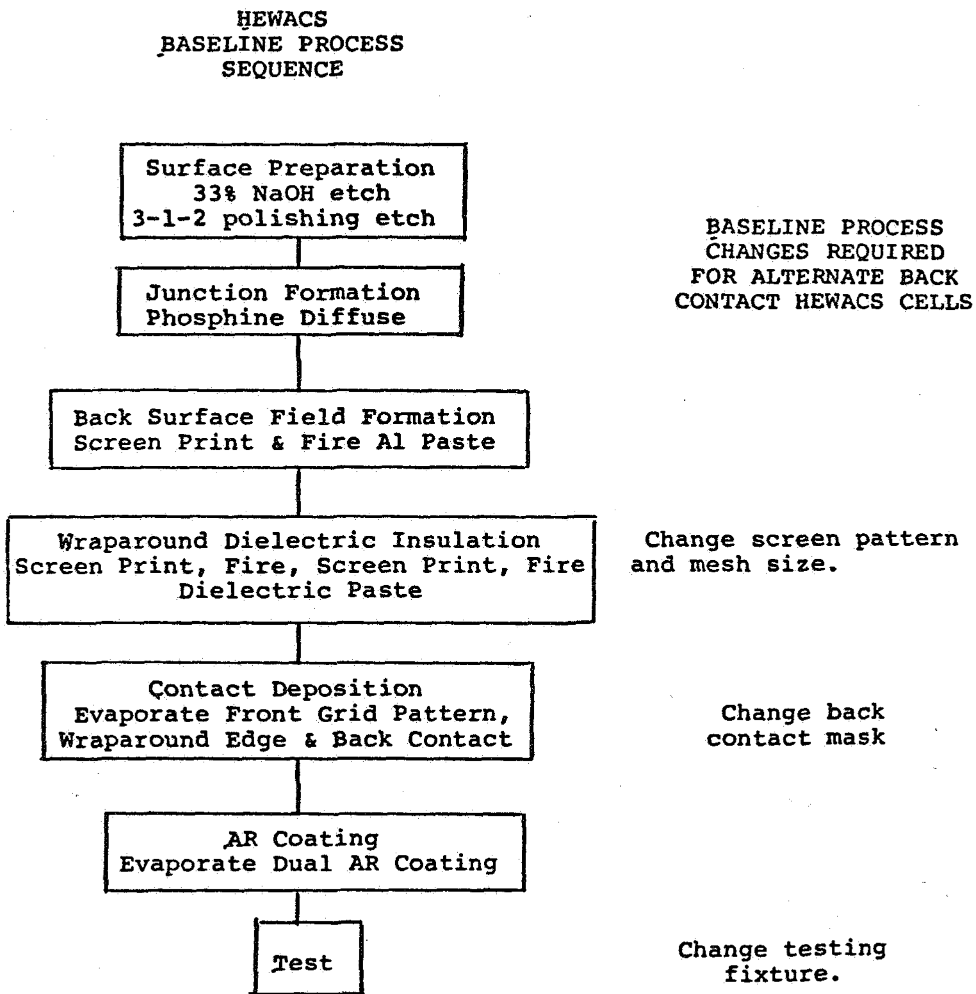

FIGURE 4

FLOW CHART AT LEFT SHOWS BASELINE PROCESS SEQUENCE USED TO MAKE THE HEWACS BASELINE CELL. PROCESS CHANGES REQUIRED TO MAKE THESE CELLS WITH THE RECONFIGURED BACK CONTACT ARE LISTED TO THE RIGHT, OPPOSITE EACH RESPECTIVE PROCESS STEP.

	V_{oc} mV	I_{sc} mA	V_{mp} mV	I_{mp} mA	P_{max} mW	EFF %	CFF -	Yield %
BASELINE HEWACS CELL @ 25°C (Average based on 4 cell lots)	623	326	514	302	155.2	14.3	0.764	71
RECONFIGURED CONTACT HEWACS CELL @ 28°C (Average based on 2 cell lots)	612	324	504	302	152.3	14.0	0.767	70

*Both cell types have single-layer AR Coating

Figure 5

CELL PERFORMANCE COMPARISON BETWEEN BASELINE CELL AND ALTERNATE BACK CONTACT CELL