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Workshop on Materials Science and Physics of Non-Conventional Energy Sources

(30 August - 17 September 1993)

"The Technology PV Issue for Industrial Applications"

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WORKSHOP ON MATERIALS SCIENCE AND PHYSICS OF NON-CONVENTIONAL ENERGY SOURCES

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Lecture note on

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INTRODUCTION

Let us image a PV learning diagram divided in three zones as follows:

- 1° zone - cost is not an issue; reliability, negligible environmental impact and reasonable conversion efficiency must be proved.

- 2° zone - the objective is to render the PV cost effective for covering a large share of the most urgent demand both small utilities in remote areas end energetically more significant needs as for example substituting diesel generators in several islands.

- 3° zone - concerning grid integrations of roof-mounted and other dispersed PV systems.

The first phase can be considered successfully concluded. Consumers have been responding well in those small market nikes where applications seemed hard to implement or leading to prohibitive cost, thus confirming the reliability of PV products.

The second phase is still in progress. Several results have been obtained but there is still much to be done and the need for further research and development is urgent to increase the efficiency cost ratio. To ensure a reasonable profit to the PV Industries the price of the W_p in module should range at present from 5 to 6 U.S.$ (1993); to render the product competitive in a large range of uses the module W_p price must not exceed 3 - 4 U.S.$ depending on the kind of application.

At present this discrepancy is probably the main cause of the limited market and of the frequent dumping. To cut the price of the W_p of a module to 3 $ it is necessary to obtain the support of public funds to substain demand and to stimulate research.

Concerning the third phase, where a further reduction to approximately 2 $ module W_p is necessary, several studies and experiments are under way. The Rokko Center (Japan, NEDO Project) is probably the most significant experimental area where stand-alone and grid connected roof-mounted PV generators can be assessed. In Europe the largest plant (600 KW) built to demonstrate the feasibility of grid connected PV systems has been installed by ENEA (Italian Agency for Alternative Energy) in Manfredonia (FG) while the first multimegawatt plant (3 MW) is being installed in Serre (SA) by ENEL, the Italian Electrical Power Company.

To increase the efficiency-cost ratio, the PV Industry is engaged in several activities, from the feedstock to the system.

PV SILICON FEEDSTOCK

Despite the enphasis put since 1980 on low cost PV grade feedstock, nowadays all PV manufacturers are using off-grade and scrap from Semiconductors Electronic Industry. Rather costly purification processes of metallurgical grade like special silane way and multiphase plasma seem appropriate to substitute the semiconductor industry waste, estimated as approximately 1000 metric tons/y, when the growth of PV marketing will cause a shortage. In any case very low cost and proper feedstock will never be available. To reduce feedstock demand, the crystallization techniques should be contemporaneously as cheap as possible and suitable for high conversion efficiency; the wafers thickness and the kerf losses must be minimized too.

INGOT TECHNOLOGIES

- **Casting**
  The casting technique in its original sense, that is filling a melt into a form or die, could offer an output orders of magnitude higher than usually obtained with conventional crystal growing methods, affected by limited dissipation of the heat of crystallization and by a very critical growth rate in maintaining the desired structure. Nonetheless the degree of impurities and the crystallografic degree of perfection must be adequate if good efficiency is desired. Past experience clearly demonstrated this aspect when attempts were made to use wafers from casting ingot. The interaction of impurities with extended crystallografic defects as grain boundaries, twins and dislocations is the main source of recombination centers which limit the minority carrier diffusion length and the lifetime of the material.

- **Directional solidification**
  At present the directional solidification is the most used technology for manufacturing

relatively large scale production of silicon ingots for terrestrial applications.

Two basic techniques are generally utilized:

a) both container and heating system are in fixed position and the temperature profile is changed by reducing the heating energy. Heat Exchanger Method (H.E.M.), where a gradual reduction of the heating current is combined with a localized heat extraction by a Helium jet stream, represents a modification of this technique with a convex solid liquid interface front.

b) the container is moved and rotated within a fixed temperature profile giving rise to solidification from bottom to top. The lower temperature of the crucible walls compared to the silicon melting point causes a radially downward directed heat exctraction with a consequent concave solid liquid interface front. By forcing a defined temperature gradient onto the side walls of the mold and very well controlling the heat flow trough the bottom, a planar solidification interface has been obtained.

- **3-Grain fast CZ**

An attractive approach to produce silicon ingots for low cost high efficiency solar cells was taken by devising a stable CZ process for growing ingots with a preselected orientation to achieve:

a) high yield continous process

b) fast growth rate

c) excellent electrical and structure properties

d) easy ultrathin slicing

The feedstock could be conventional polysilicon, remelt and experimental semiconventional solar grade products. The seed was prepared by joining 3-crystals[110] oriented; to the host crystal two crystals were added as first order twins generating between them a secon order twin.

Peculiarity of 3-grain ingot is that only {111} planes perpendicular to the melt take part in bounding the ingot, as proved by the presence of only mirrorlike facets on the outer surfaces. Since the {111} bounding planes are vertical and the {111} oblique are tightened on the twins planes so that they do not behave as cleavage planes, these 3-grain <110> crystals are probably the most suitable for ultrathin slicing. The yield of the slicing process is over 90% for approximately 200 μm thick wafers (120 μm kerf) and almost the same yield seems obtainable for the wafers with a thickness of 80 μm we are currently experimenting with.

CELL TECHNOLOGY

The thick film process sequence, based on texturization and/or antireflective coating, thermal or printing diffusion and screenprinted contacts has been proved to be adequate for low cost, large scale production. It has been demonstrated at lab level that it is possible to process ultrathin wafers without significant breakages provided that the equipment is properly automated.

A few years and significant investments are necessary before the majority of PV industries can reach such a high level of automation.

CONCLUSIONS

To process ultrathin (<100 μm) wafers without breakages and with a high efficient (15%) cell technology is still a matter of research, but it seems the only way for creating the technological platform necessary to lower the price and to initiate an overall strategy in the field of grid connected applications. As far as long range goals are concerned it is not possible as yet to foresee which technology and which materials (ultrathin crystalline with very highly cell efficiency, ribbon with high throughput, thin films, multijunctions...) will adequately contribute to satisfying the demand for large scale energy needs.