APPLICATION OF NONDESTRUCTIVE EVALUATION (NDE) IN ASSESSING THE STATE-OF-HEALTH OF PHOTOVOLTAIC SOLAR ARRAYS

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ABSTRACT

The U.S. Department of Energy's program to develop photovoltaic solar arrays by 1986, that have a useful life of twenty years with a selling price of fifty cents per watt, has resulted in a new rapidly advancing photovoltaic industry and technology. Current projections based on current solar module hardware experience indicate that the 1986 electrical performance and cost goals can be met. However, field exposure experience with newly formulated solar cell configurations and encapsulation material systems is very limited, and the long-term, life-limiting failure modes and degradation rates have yet to be determined.

To develop a data base for life prediction and performance degradation rate measurement a number of new and state-of-the-art NDE methods are being evaluated for laboratory and field use in detecting flaws, failures and subtle material changes in experimental solar modules. In addition to the normal visual, photographic, and electrical performance measurements being made, several new techniques show promise of practical application.

INTRODUCTION

Photovoltaic solar arrays for the direct conversion of sunlight to direct current electrical power may consist of large numbers of individual flat plate solar modules generating about ten watts (peak power) per square foot of solar cell surface area. A 25 kilowatt solar array at the University of Nebraska Agricultural Experiment Station shown in Fig. 1 indicates the type of hardware for which NDE techniques are sought.

The objectives of these NDE measurements (Fig. 2) are to determine or identify by cost-effective techniques (1) the changes in array performance, (2) the failure modes and their causes, (3) quantitative degradation rates, and (4) incipient failures in operational solar modules.

Figure 4 shows the current standard laboratory performance measurement technique which is a large area pulsed solar simulator (LAPSS) manufactured by Spectrolab Inc. A pulsed xenon arc lamp provides one sun of uniform illumination of short duration without solar cell heating. The output terminals are swept by an electronic load during the pulse and the data stored. The module current-voltage (I-V) curve corrected for temperature and illumination is plotted automatically. Analysis of these curves identifies changes in the internal characteristics of the photovoltaic circuit.

OTHER NDE APPROACHES EVALUATED

Infrared Camera - With large numbers of solar cells connected in series, the degradation of one cell can cause localized overheating and subsequent module failure. The infrared camera may be used in the field and laboratory to detect and locate overheating and identify its cause as in Fig. 5.

Laser Scanner - Figure 6 outlines the operation of a solar cell laser scanner. A focused laser beam is deflected in a raster pattern over the cell surface, generating a photocurrent which varies from point to point due to localized defects in the cell structure. The amplified current is used to produce a module image on a cathode ray tube where cracked and inoperative cells are revealed.

Partial Corona Discharge - Figure 7 shows the test equipment and typical output data used to detect partial corona discharge in a photovoltaic module due to incipient voltage breakdown between the solar cell circuit and the grounded supporting frame. Although single solar cell voltage output is only 0.5 volt, solar cells may be series connected to produce solar array output voltages of 1000 Vdc in utility power generation applications.

FTIR - A direct measurement of chemical degradation changes occurring in the exposed solar module encapsulant materials (polymers) is possible by taking small specimens of polymer from the layer of encapsulant surrounding an operational cell and conducting a Fourier Transform Infrared (FTIR) spectroscopic analysis (Fig. 8) to measure the time-related production and loss of chemical species. A subsequent step would be to relate these chemical changes to physical and electrical degradation.

Ultrasonics and Ellipsometry - Figures 9 and 10 show the detection and imaging capabilities of ultrasonic and ellipsometric techniques applied to solar modules. The focused ultrasonic probe readily identifies the encapsulant/cell interface and the differences between bonded and disbonded conditions. At this time, however, the technique does not reveal the quality of the bond itself. Ellipsometric surface analysis reveals first surface conditions and surface contamination but does not provide an effective assessment of interface phenomena.

CONCLUSIONS

Performance measurement and failure detection techniques are furthest developed. Still needed are degradation rate techniques for field tracking and life prediction.

ACKNOWLEDGMENTS

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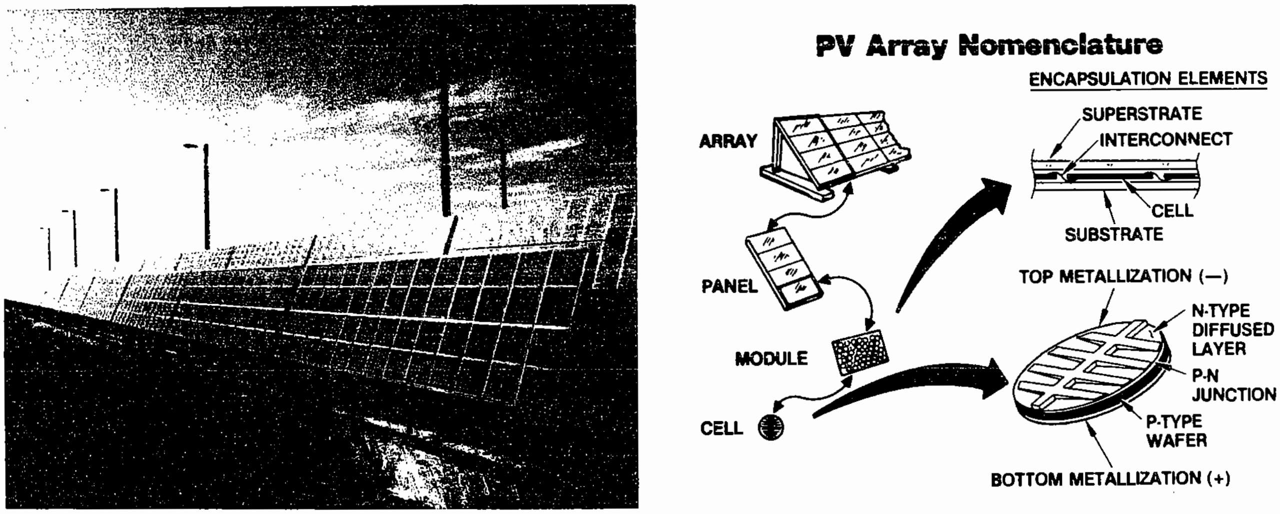


25 KILOWATT SOLAR ARRAY AT UNIVERSITY OF NEBRASKA. MEAD AGRICULTURAL EXP. STATION – IRRIGATION AND CROP DRYING APPLICATION

ELEMENTS OF A PHOTOVOLTAIC SYSTEM – NDE TECHNIQUES HAVE HIGH POTENTIAL FOR APPLICATION AT MODULE AND ENCAPSULATED CELL LEVEL.

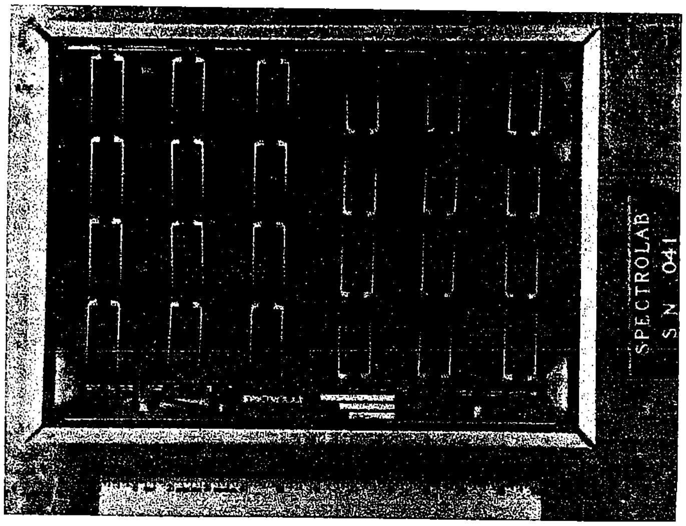
Fig. 1. Photovoltaic Arrays - Energy From the Sun

Objective —

Apply NDE Methods to Solar Arrays in Order to:

- QUANTIFY CHANGES IN PERFORMANCE
- IDENTIFY FAILURE MODES/CAUSES
- ESTABLISH DEGRADATION RATES
- IDENTIFY INCIPIENT FAILURES

Fig. 2. Objective



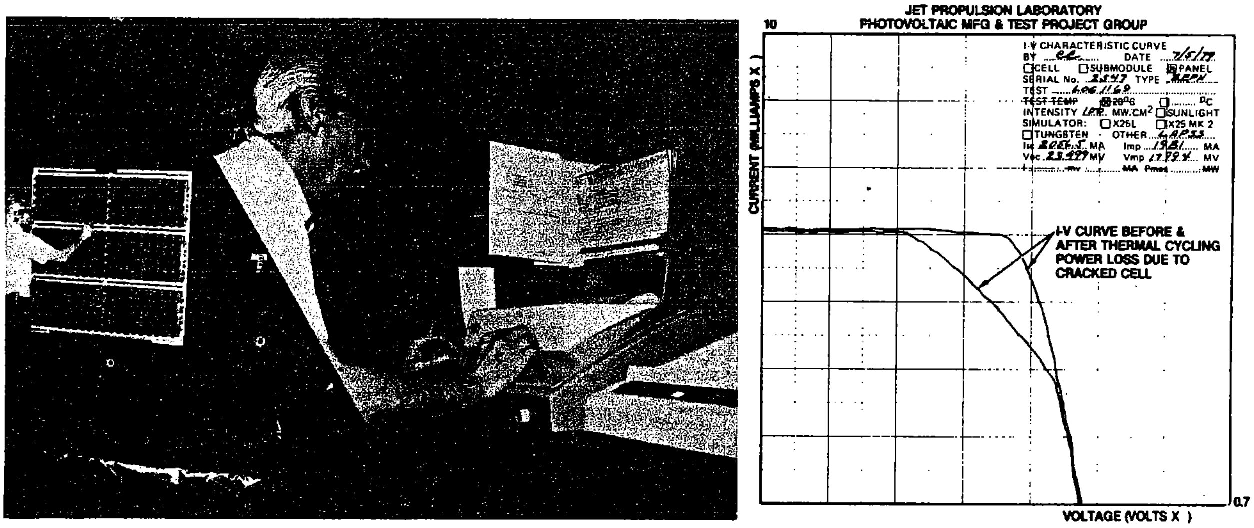
MFG. – SPECTROLAB INC.
SUN VALLEY, CA.

OUTPUT – 5 WATTS @
6 VOLTS DC

ENCAPSULATION –

- GLASS SUPERSTRATE
- POLYVINYL BUTYRAL
- MYLAR MOISTURE BARRIER
- ALUMINUM SUPPORT FRAME

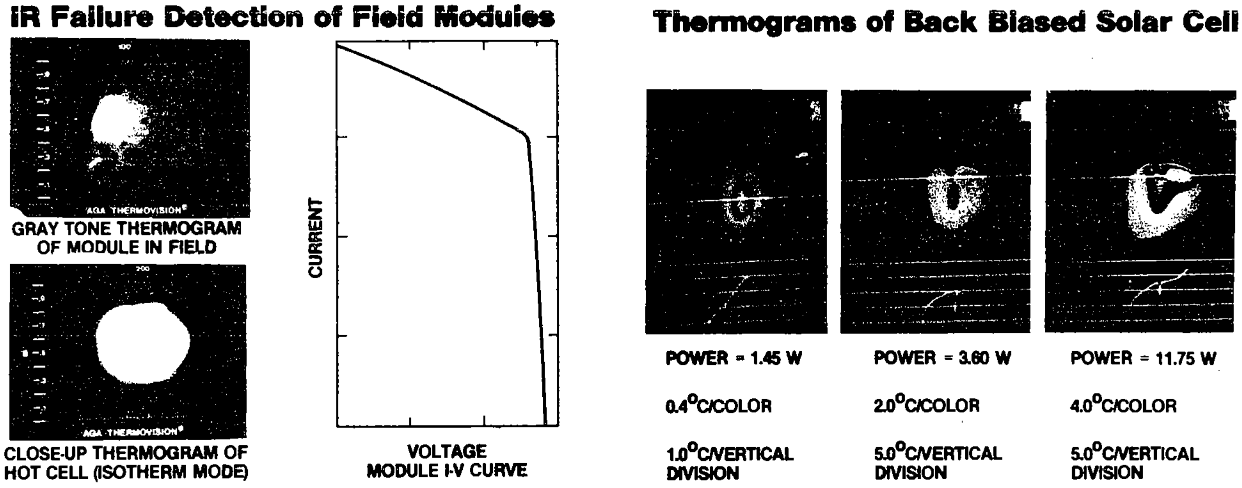
Fig. 3. Photovoltaic Module - 2nd Generation



LARGE AREA PULSED SOLAR SIMULATOR (LAPSS) MANUFACTURED BY SPECTROLAB. PULSED XENON ARC FOR UNIFORM ILLUMINATION WITHOUT CELL HEATING. MODULE OUTPUT SWEPT BY ELECTRONIC LOAD & DATA STORED.

POWER I-V CURVE CORRECTED AND PLOTTED AUTOMATICALLY. ANALYSIS OF CURVES IDENTIFIES TRANSMISSION LOSSES & CHANGES IN INTERNAL RESISTANCE.

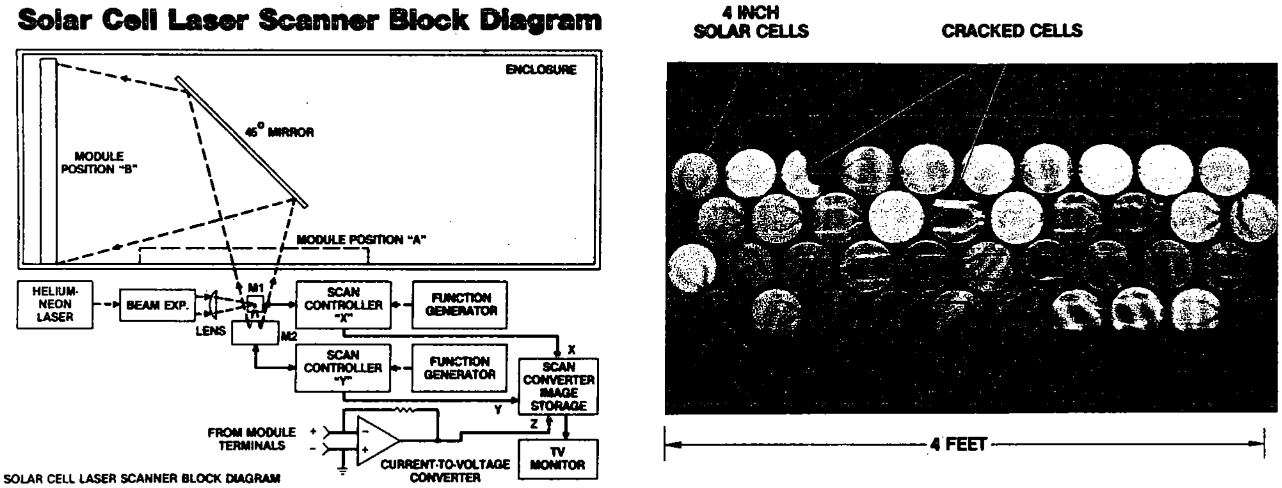
Fig. 4. Solar Module Power Output



PORTABLE IR CAMERA USED TO LOCATE MODULE IN FIELD OPERATING WITH DEGRADED PERFORMANCE DUE TO CRACKED CELL – SUBSEQUENT IV CURVE (RT.) CONFIRMED REDUCED ELECTRICAL PERFORMANCE

NON-UNIFORM HEATING OF A SOLAR CELL DUE TO MODULE SHADOWING INDUCED BACK-BIASED OPERATION. THERMAL MAPPING PIN-POINTED INCIPIENT CELL JUNCTION FAILURE LOCATION

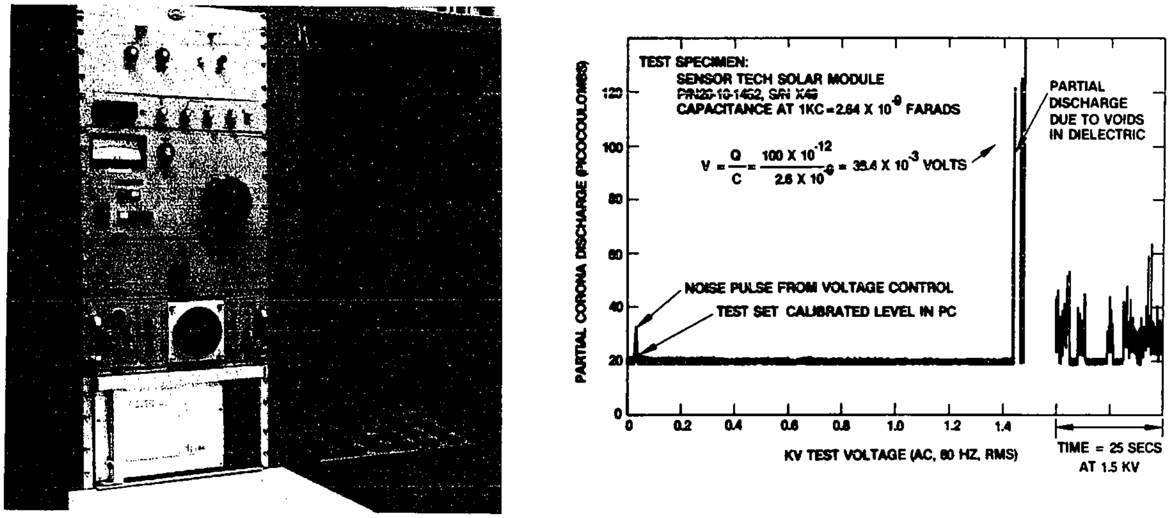
Fig. 5. Infrared Camera



JPL LASER SCANNING SYSTEM AMPLIFIES OUTPUT OF ILLUMINATED SPOT ON CELL TO PRODUCE POSITION KEYED VIDEO IMAGE. ONLY FUNCTIONAL PORTIONS OF SOLAR CELLS RESPOND TO INCIDENT SWEPT LASER BEAM

SOLAR CELL MODULE LASER SCAN CONFIRMED THAT REDUCED ELECTRICAL PERFORMANCE WAS CAUSED BY 2 CRACKED CELLS NOT DETECTED BY X10 POWER VISUAL INSPECTION

Fig. 6. Laser Scanning For Solar Cell Evaluation



TEST EQUIPMENT DETECTS PARTIAL CORONA DISCHARGE (IN PICOCOULOMBS) DUE TO INCIPIENT DEFECTS IN CONSTRUCTION OR ENCAPSULATION OF SOLAR MODULES

PHASE RELATION AND INITIATION VOLTAGE OF PARTIAL DISCHARGE IDENTIFIES INCIPIENT FAILURE DUE TO VOIDS WITHIN DIELECTRIC ENCAPSULATION SYSTEM – IDENTIFIED AS AIR BUBBLE TRAPPED UNDER A SOLAR CELL

Fig. 7. Partial Discharge (Corona)

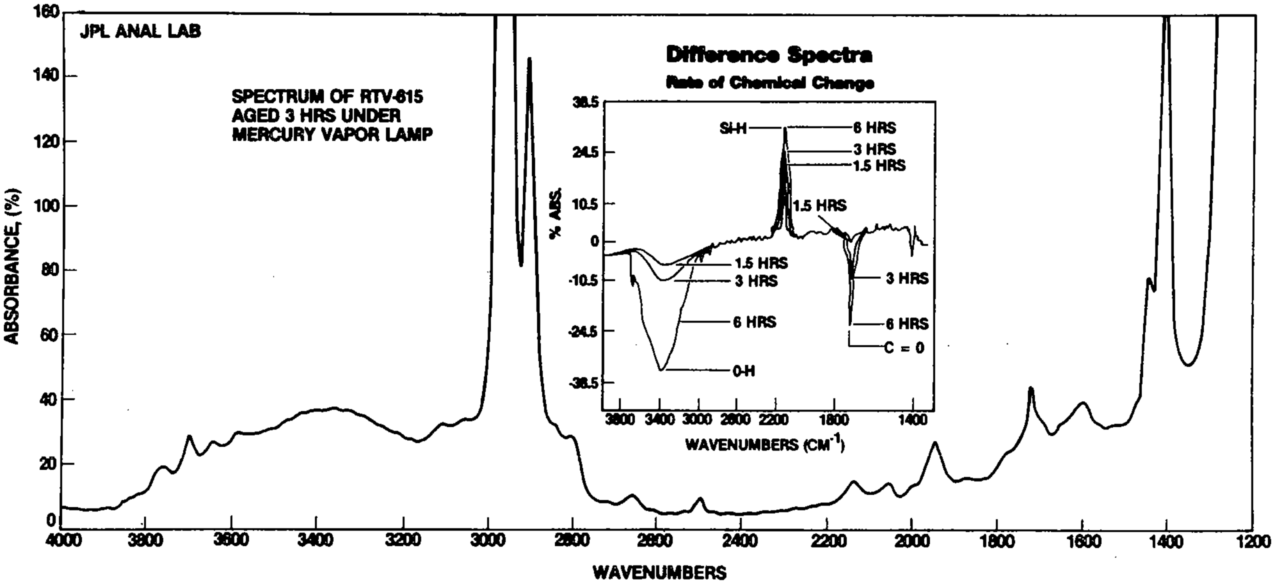
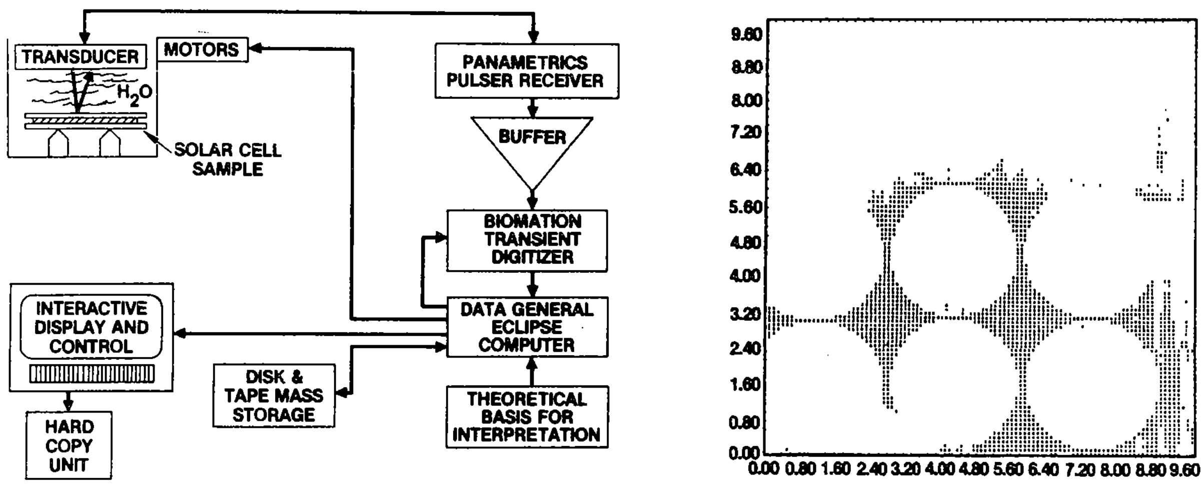


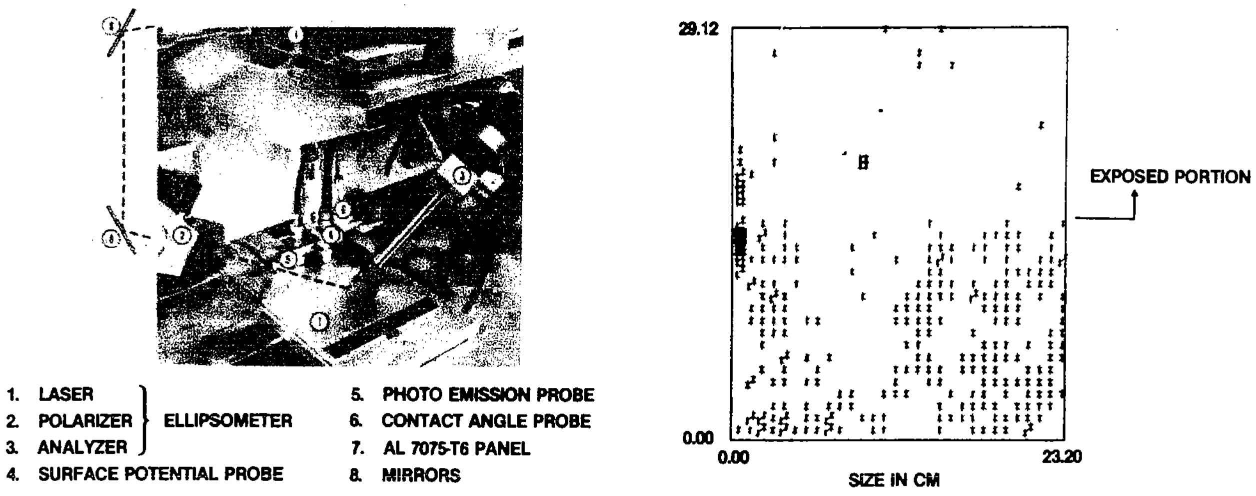
Fig. 8. Fourier Transform Infrared Spectroscopic Analysis of Silicone Pottants (Biopsy Specimen)



BLOCK DIAGRAM OF COMPUTERIZED ULTRASONIC SYSTEM FOR TESTS OF SOLAR CELL MODULES IN STUDY OF DEBOND DETECTION

ULTRASONIC MAP OF NULLED REFLECTION FROM THE ENCAPSULANT TO SILICON SOLAR CELL INTERFACE

Fig. 9. Ultrasonics



ELLIPSOMETER MULTIPROBE FACILITY AT ROCKWELL SCIENCE CENTER USED FOR INTERFACE ANALYSES

DIFFERENCE OFF NULL ELLIPSOMETER MAP OF SOLAR MODULE PARTIALLY EXPOSED TO ULTRAVIOLET & MOISTURE

Fig. 10. Ellipsometer