TERRESTRIAL SILICON ARRAY FIELD AND TEST EXPERIENCE*

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The key building block of a photovoltaic system utilizing flat plate silicon solar arrays is the solar cell module. The solar cell module consists of a collection of solar cells electrically interconnected in series/parallel and encapsulated into a mechanical package which provides for structural support and protection from the terrestrial environment. In the system, the modules are interconnected to form solar arrays consistant with the current and voltage requirements of the particular application.

The design of solar cell modules, like any design, is based on providing an optimum compromise between the competing demands of improved system integration, higher reliability/lifetime, and lower manufacturing cost. A key consideration in the design of solar cell modules is the identification and resolution of the life-limiting or safety-related failure modes and mechanisms.

The most important information on failure modes of silicon flat-plate solar cell modules has come from field experience. As indicated in the subsequent viewgraphs there are six key failure modes currently encountered with flat plate silicon modules.

- Electrical Interconnect Breakage
- Solar Cell Cracking
- Encapsulant Cracking & Delamination
- Cell Metalization Deterioration
- Electrical Insulation Breakdown
- Optical Surface Soiling

These failure modes are listed in approximate order of severity in early modules of the pre-1976 time period. In recent years electrical

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interconnect breakage, metalization deterioration, and electrical insulation breakdown have been substantially solved. Considerable progress has also been made in the remaining areas. It is probably safe to assume that these same failure modes will be important in thin film arrays.

The approach used to solve the early module design weaknesses is based on identifying the failure mechanisms and engineering a design solution. A difficult aspect is assessing the adequacy of the solution or comparing the relative strengths of alternate solutions in a short time period. This has been addressed through the use of qualification tests designed to environmentally stress the modules and precipitate failures expected in field use. Selection of the test environments is a difficult task based on engineering judgement and extensive test experimentation. Correlation with the actual field environment, where it exists is based primarily on historical (empirical) evidence. Direct correlation is rarely achieved due to the unknown nature of the actual field environment and the generally unknown sensitivity of the failure mechanism to the accelerated test environment.

Those environmental tests found to be most useful in module design qualification, or screening are described in the viewgraphs. Of these the thermal cycle, humidity and structural tests have proved to be excellent. Ultraviolet testing has been found to be difficult to interpret and unreliable to date. Research on ultraviolet-humidity, bias-humidity, and module soiling tests is actively being pursued within the silicon program. Additional tests are examined for use when field failure mechanisms are identified which are not precipitated by the current environmental tests.

LOW-COST SOLAR ARRAY PROJECT
KEY FAILURE MODES AND MECHANISMS

- ELECTRICAL INTERCONNECT BREAKAGE
  - THERMAL CYCLING
  - WIND LOADING
- SOLAR CELL CRACKING
  - THERMAL CYCLING
  - HAIL IMPACT
- ENCAPSULANT DELAMINATION AND CRACKING
  - THERMAL CYCLING
  - HUMIDITY
  - ULTRAVIOLET
- CELL METALLIZATION DETERIORATION
  - HUMIDITY (BIAS-HUMIDITY)
- ELECTRICAL INSULATION BREAKDOWN
- OPTICAL SURFACE SOILING

LOW-COST SOLAR ARRAY PROJECT
ENVIRONMENTAL QUALIFICATION TESTING

- OBJECTIVE:
  - UNCOVER POTENTIAL FIELD FAILURE MODES AND MECHANISMS TO ALLOW FOR THEIR ASSESSMENT AND CORRECTION
- APPROACH:
  - SUBJECT MODULES TO CAREFULLY CHOSEN EXTREME ENVIRONMENTS WITH KNOWN IMPORTANCE
- PHILOSOPHY:
  - MINIMUM TEST COMPLEXITY TO REDUCE COST
  - MAXIMUM TEST STABILITY TO ALLOW CORRELATION AND COMPARISON

LOW-COST SOLAR ARRAY PROJECT
KEY ENVIRONMENTAL TESTS

- CURRENT PRACTICE
  - THERMAL CYCLING: -40 TO +90°C, 50 CYCLES
  - HUMIDITY: MIL STD 810°C, 507.1, V
  - MECHANICAL CYCLING: ±50 lb/ft^2, 10,000 CYCLES
  - TWISTED MOUNTING SURFACE: 1/4 in/ft
  - HAIL IMPACT: ICE BALL PROJECTILES
  - VOLTAGE BREAKDOWN: 1500 VOLT HI-POT
- UNDER DEVELOPMENT
  - OPTICAL SURFACE SOILING
  - BIAS-HUMIDITY
  - UV-HUMIDITY

LOW-COST SOLAR ARRAY PROJECT
OTHER TESTS

- SPECIAL ENVIRONMENTS
  - SALT FOG
  - FUNGUS
- TESTS HAVING LITTLE EFFECT
  - HUMIDITY-FREEZING
  - HEAT-RAIN
  - WIND DRIVEN RAIN
  - WEATHEROMETER
  - SHIPPING SHOCK AND VIBRATION
  - DUST ABRASION