SOLAR PHOTOVOLTAIC RESEARCH AND DEVELOPMENT PROGRAM OF THE AIR FORCE AERO PROPULSION LABORATORY

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The Air Force space program has continuing requirements for increased power system capability in terms of volume, area, weight, life, power level, and survivability. Figure 1 shows our goals in these various areas. Nuclear radiation survivability has generally been accomplished, but the degradation on exposure to the particulate species of nuclear weapon effects still requires improvement.

The laser weapon effects program again is primarily aimed at survivability for certain dose levels as well as determination of the thresholds for failure of the various solar cell array configurations. Much of this background has been acquired in continuous wave radiation, and approaches to minimize degradation are under development in the SMATH programs conducted under the AF Materials Lab contracts. The pulsed laser effects area is just beginning investigation, and the program initiated in FY79 is addressing several laser wavelengths and pulse durations. For the first time also we are attempting to handle advanced cell assemblies, i.e., high efficiency silicon, GaAs, and multiband gap if sufficient cells are fabricated in the next three years. The effort is irradiating both cw and pulsed laser species.

The silicon solar cell concepts investigated include textured, planar cells for ESB, various field combinations and non-reflecting vertical junction combinations. Funding from basic research exploratory development and advanced development are utilized. The basic research work deals with theoretical efforts as well as experimental investigation of effects of selected dopants such as gallium in high purity silicon. The HESP II silicon advanced development program contractor reported 16% efficiency in a textured cell configuration with 2 Ω-cm silicon. Because of high α the modeling of this cell in orbit results in a temperature of 10 to 15 C° higher, negating most of this gain. For this reason we have also supported development of planar silicon cells with multilayer antireflective coating, yielding 14.8% efficiency at 25° C. This cell is slightly better than the textured cell at operating temperature. Vertical junction solar cell work is directed toward 16 to 18% initial efficiency with 14% after 10^{15}, 1 MeV e^-/cm^2 equivalent radiation. Technology appears in hand for 15% initial efficiency without fields or use of optimum geometry. With back surface field to enhance voltage and geometry optimization, we hope to approach 16% efficiency. The high-purity, high-lifetime silicon from our basic research effort may also help out both initial and end-of-life efficiency.

The relationships of our near, intermediate, and long term solar cell development are shown in figure 2. The current GaAs cell program was initiated in 1976 and we have achieved better than 17% in the laboratory with radiation resistance superior to that of silicon up to $5X10^{15}$, 1 MeV e^{-}/cm^{2}. Companion programs to this GaAs cell development are the development of dendrite ribbon material and the development of solar array panel technology presently under negotiation for a FY79 start. This technology, when developed, should yield 50% greater end-of-life power at orbit temperature. The multiband-gap cell work is aimed at an initial efficiency of 25% and is considered relatively high risk because of the problems of lattice mismatch and band-gap matching required. (Dr. W.P. Rahilly discusses this in greater detail.) This technology will not come on line before the mid 80's and is very important to our weight, volume, and area goals for satellite power systems.

In addition to weapon effects and cell technology efforts, we are also initiating a high-voltage hardened, high-power system technology program. For the first time we are also addressing thermal energy management. The effort is directed toward future requirements in the 5 to 50 kW range and power densities of 6 to 12 W/lb. Weight reductions in all facets of power system technology, including batteries, are needed to achieve this capability. This effort also addresses Shuttle compatibility and modular power system component technology.

The present weight limit on satellites in synchronous orbit is about 3300 lb using a Titan III C and high-energy second stage. With the advent of the Shuttle and the use of the inertial upper stage (IUS) this weight capability increases to 5200 lb. Figure 3 shows the power system capability in this scenario. Present capability could insert 4.3 kW satellite BOL power. With the introduction of the two intermediate concepts of GaAs cells and NiH_2 battery, we can boost this power to 8 kW. Advanced technology can go to an 11 kW power level without an orbit assembly. Lower altitude orbits can, of course, accommodate higher weight vehicles and correspondingly higher power levels.

- SPACE: HIGH EFF. WEAPON HARD, LONG LIFE, LIGHT WEIGHT, LOW VOLUME, LOW COST
- NUCLEAR WEAPON HARDEN SI PRESENT - HASP
  APPLY TO ADVANCED CELLS SI, GaAs
- LASER HARDENING C.W. - UNDERSTAND - APPROACHES IN DEV.
  PULSED - PROBLEMS BEING DEFINED, INITIATE DEV.
- SOLAR CELL CONCEPTS
  - NEAR TERM: SILICON HESP II 16% 12% EOL
    NRVJ 14% EOL
    6.1 MATERIALS
  - INTERMEDIATE: GaAs HESP II 16% EFF. OPER.
    ULTIMATE 18-20% EFF. 1983
  - LONG TERM: MULTIJUNCTION 25% EFF. 1985
    30% 1990

Figure 1. - Solar power R&D objectives (AFAPL).

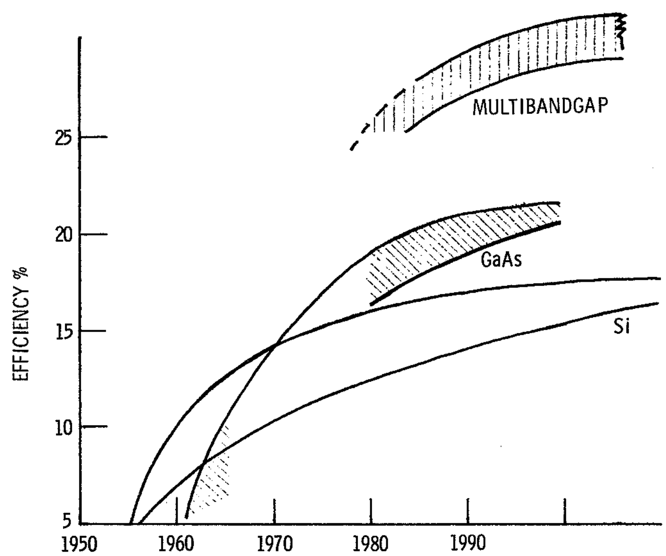

Figure 2. - Solar cell efficiency as function of time.

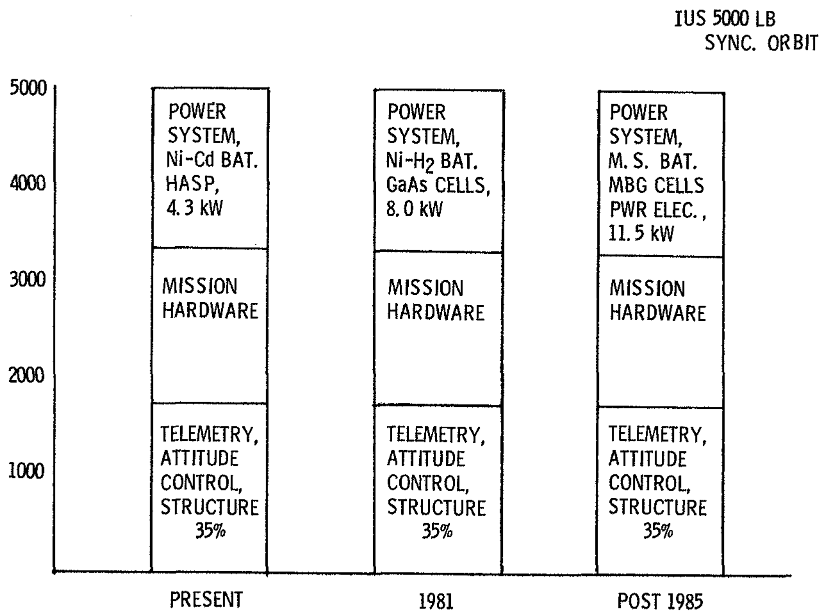

Figure 3. - Power-component payoff in synchronous-orbit satellites - high-voltage, high-power, hardened system.