20000. GTP also produces polymers with linear backbones, in contrast to free radical polymerization in which branching may occur. One of the problems yet to be solved in GTP and metal-free polymerizations is the control of tacticity.[14]

As far as industrial applications are concerned, Dupont has invested great efforts towards developing such products as star polymers for use in toughening plastics and coatings, e.g., for the automobile industry. It remains to be seen whether the customer will pay a higher price for a more durable product. Other potential applications include thermoplastic elastomers, non-aqueous dispersions for the control of rheological properties,[7] and liquid crystalline polymers.[15] Chiral polymers made by GTP have also been reported.[16]

Although metal-free polymerization has only recently been developed, similar applications are in principle possible. The mechanism and theoretical basis also need to be explored. Finally, the question arises whether other types of anionic polymerizations (e.g., ring opening processes) can also be performed using metal-free initiators.

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Conference Report

Photovoltaic Solar Energy in Europe

More than 750 materials scientists, physicists, engineers, marketing specialists, and government officials from 45 countries met from 9-13 May 1988 at the "8th European Photovoltaic Solar Energy Conference and Exhibition" in Florence, the largest European Conference ever held on this topic. Photovoltaic (PV) energy has now reached maturity. Crystalline and polycrystalline silicon modules have proven to be the most reliable decentralized source of energy. Their still rather high cost limits their applications at present to the electrification of isolated sites, which are however abundant. Performance and reliability of standalone PV systems in the 10 W to 60 kW range have been evaluated during the past ten years by the US Army, several American and European agencies, and by Third World organizations.

Whereas the reliability of crystalline and polycrystalline silicon modules complies with military standards, many peripherical components such as inverters and battery regulators still have reliability problems. For most household applications, low voltage direct current is therefore preferable to 220 V alternating current, in spite of the high price and poor choice of dc household appliances. The storage of electrical energy has turned out to be a crucial problem for photovoltaics. According to *E. Voss* (Varta, Kelkheim), the lead-acid battery is at present the only viable system for power applications. Possible alternative storage systems for the future are Zn-Br and Cr-Fe batteries, whereas Ni-Cd batteries will not be cost-competitive.

Progress in photovoltaics is intimately linked with the development of new materials and processing technologies. Amorphous hydrogenated silicon, discovered as an electronic material by *Spear* and *Lecomber* (University of Dundee) in 1975, is today a $ 200 million per year business in non-PV applications, and has become one of the leading thin film solar cell materials.

Progress that has recently been made in the production of silicon cells is mainly due to the minimization of optical and recombination losses. Crystalline cells with recombination-free interfaces have been developed by *M. A. Green* in Kensington, Australia (passivated emitter and lasergrooved buried contact), and by *R. Swanson* of Stanford University (point contact cell). Light trapping is used now in all kinds of silicon solar cells, and has given a spectacular improvement in conversion efficiency. It enhances the optical path of poorly absorbed red or near-infrared light and allows one to make cells thinner. Thin amorphous silicon cells show less light-induced degradation than thicker ones.

The search for a low band-gap a-Si alloy for solar cells has not yet given conclusive results, as pointed out by *J. Bullot* (Orsay University), since the reproducibility and electronic quality of silicon-germanium alloys are not yet satisfactory. The recent improvement in conversion efficiency of a-Si p-i-n cells is mainly related to the p-doped window layer: microcrystalline a-$Si_{1-x}C_x$:H layers, doping with $B(CH_3)_3$ instead of B_2H_6, and superlattice p-layers. Efficiencies of 10% (active area) for $10 \times 10\ cm^2$ modules were announced by Sanyo (Osaka). *D. Carlson* (Solarex, Newtown, PA) reviewed in-line processing technology for large area a-Si modules. Initial efficiencies of 8% on 1000 cm^2 modules are currently achieved by several American and Japanese companies. Stability of a-Si cells has greatly improved. Light-induced degradation can be reduced to 15% in very thin (0.2 to 0.3 μm) cells.

Polycrystalline cells have seen spectacular progress, too, both in fundamental research (*L. L. Kazmerski*'s (SERI, Denver)talk on the analysis of hydrogen at grain boundaries by scanning tunneling microscopy was one of the highlights of this conference) and on the technological side. *A. Barnett* (University of Delaware) reported efficiencies of over 12.5% with small polycrystalline cells processed on low-cost ceramic substrates.

Non-silicon materials are outsiders in PV technology. In spite of the high price of indium, $CuInSe_2$ continues to attract much attention, especially due to progress in material processing (sputter and spray methods). Stacked a-Si/$CuInSe_2$ cells were described by ARCO. Economic criteria will determine the future of this technology.

It remains an open question whether crystalline, polycrystalline or amorphous silicon will be the leading material for the solar cell technology in the next century. Amorphous silicon seems to have the highest potential for cost reduction. However, this requires large scale plants (well above 1 MW/year), since the initial investment is very high.

The vigorous financial effort of the Commision of the European Comunity and national governments (especially in West Germany) to encourage photovoltaics research and development in Europe has so far been a success. 35 companies exhibited PV modules and systems and showed that photovoltaics is already an industrial reality.

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Research News

Lord Kelvin Updated

William Thompson, better known to science as Lord *Kelvin*, demonstrated theoretically as long ago as 1853 that the rate of temperature change in a cyclically loaded body is directly related to the rate of change of the sum of the principal stresses, if conditions are adiabatic. If a specimen is stressed inhomogeneously, in cyclic fashion, then the distribution of stresses is expressed by a distribution of mean ΔT (relative to the undisturbed temperature of the sample). The ΔT oscillate with the same frequency as the applied cyclic stress. (An increasing tensile stress gives a temperature fall, an increasing stress, a temperature rise.)—Kelvin's principle can be thought of as the thermoelastic analogue of Faraday's principle of electromagnetic induction, established at roughly the same time.

Kelvin's principle has been exploited for some years now to map the distribution of stresses in an inhomogeneously stressed thin flat body—for instance, a sheet containing a hole or a notch—by measuring the time-averaged temperature change at each point by means of a scanning infrared emission camera: the camera is electronically controlled to read ΔT at each test point in synchrony with the frequency of the applied stress. The strategy has been used for non-destructive examination (NDE) of an object's resistance to fatigue damage. Here the cyclic stress is used to modify the state of the material rather than as a mere probe to examine stress distributions. Incipient fracture, or delamination of a fibre-reinforced composite, leads to enhanced local temperature changes, and such damage sites show up in *vibrothermography*—as the technique is sometimes called—long before they can be detected by any other NDE method.[1] The method has been found especially favourable for NDE of fibre-reinforced composites.[1]

However, vibrothermography can do more than provide NDE: given sufficiently sensitive equipment and appropriate theory, the distribution of stresses which would result from an applied steady load can be determined by a ΔT scan with a low-frequency cyclic load which itself is far too small to damage the specimen in any way. A new instrument based on a design by SIRA in England, named