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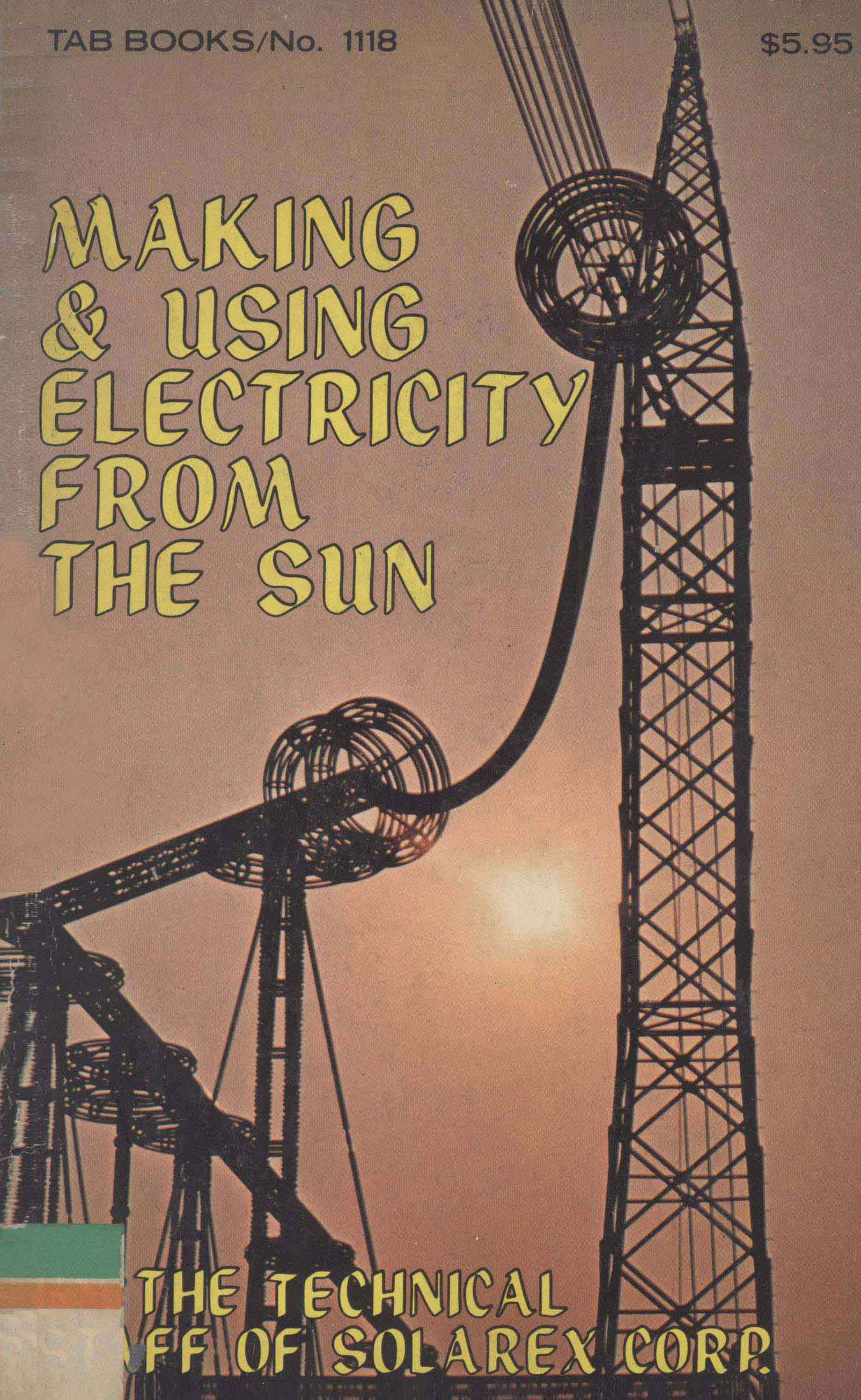
MAKING & USING ELECTRICITY FROM THE SUN



THE TECHNICAL
FF OF SOLAREX CORP.

MAKING & USING ELECTRICITY FROM THE SUN

MAKING & USING ELECTRICITY FROM THE SUN

BY THE TECHNICAL STAFF OF SOLAREX CORP.

TAB BOOKS

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Preface

The idea of being able to get useful energy from the sun has been a dream of scientists for centuries. The sun is an inexhaustible source of energy, and sunlight is available all over the earth. What is needed to utilize the energy in sunlight is some efficient way to convert the radiant energy in sunlight into some form of energy that is easier to use, such as electrical energy. The silicon voltaic cell, or solar cell as it is commonly called, is just such a device.

The photovoltaic effect, where electricity is produced when certain materials are illuminated, is not new. It was first noted by E. Becqueral in 1839. Thus the photovoltaic cell is probably the first solid-state electronic device ever invented. It is certainly much older than the radio crystal detector which has often been called the first solid-state electronic device.

The utilization of the photovoltaic cell as an energy source has been very slow, primarily because of the abundance of hydrocarbon fuels such as coal, oil, and natural gas. The first practical use of the photovoltaic effect was in selenium cells that were, and still are, being used to measure light levels. A typical example is the light meter used in photography.

The first significant use of photovoltaic cells to produce electrical energy was in the space program. Satellites need a source of electrical energy that will last for a long time without any attention. All conventional batteries will run down after a period of use. The solar cell, however, will continue to deliver electric power as long as sunlight is available.

In recent years the development of solar cells has accelerated rapidly. This is due in part to the realization that our supply of hydrocarbon fuels, while large, is not inexhaustible. Another factor that has contributed to the development of solar power sources is the increasing concern about air and water pollution resulting from the burning of hydrocarbon fuels, and a possible hazard connected with the use of nuclear fuels.

Whereas the cost of conventional fuels has skyrocketed in recent years, the cost of solar cells has been declining steadily. The U.S. Department of Energy has a stated goal of reducing the cost of solar cells to $0.50 per peak watt by 1986. Even if this goal is not completely realized, the program will make the solar cell competitive with many other energy sources.

This book is intended for anyone interested in solar cells as a source of energy for any requirement, large or small. The first three chapters are intended as background material for readers who are not familiar with either solar energy or the photovoltaic effect. Chapters 4, 5, and 6 deal with practical solar cells, how to use them, and typical applications. A separate chapter describing a few solar cell projects is included for the experimenter who wishes to build either demonstration or practical energy sources. Chapter 8 covers commercially available accessories that make installation and use of a solar electric system easier.

The last chapter deals with the use of solar cells as light sensors rather than as power sources. A glossary of terms has been included for the benefit of those not familiar with the terminology that is springing up in connection with the application of solar electricity.

Technical Staff
Solarex Corporation

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Introduction

When solar cells were invented in the early 1950's, their use for terrestrial applications was considered. At that time the cost of electricity and energy producing means was still declining, and the newly-invented solar electricity was not even in the ballpark. It might have been forgotten if the space program had not come about.

What was expensive for earth use—when oil, gas, batteries, etc. were abundant—was inexpensive for space use. The U.S. space program then brought solar cells out of the laboratory into limited production, and they became the power source for the satellites. Because of the required high reliability and the premium on size and weight, space solar cells became rather expensive and efficiency became the key word.

Solar cell efficiency improved slowly for 10 years until an abrupt improvement occurred in 1972 and a high efficiency solar cell was developed.

Although solar cells proved to be an extremely reliable and simple source of electricity for space use, due to their cost, only a small number of space reject cells were used for terrestrial applications as late as 1972. The primary reason was that solar cell technology was not applied to production of inexpensive solar cells for terrestrial use. In 1972 it was considered that the cost of solar electricity was over $100/watt compared to about $1/watt or less for conventional electricity.

Dr. Joseph Lindmayer, known for his work in solid state physics and who invented the high efficiency solar cell, and Dr. Peter Varadi, who had broad experience in materials technology and business administration, recognized that solar electricity was feasible and would be one of the most important energy sources of the future. At that time no serious effort was made by any company to develop and mass produce solar cells and generators for terrestrial use only.

With this in mind, Solarex Corporation was formed in early 1973 with the purpose of devoting its entire effort to solar energy and to advancing the state of art by progressive research and development and manufacturing.

Solarex Corporation is a leader in the development of terrestrial solar cells to convert light to electricity. It has total manufacturing capability to produce efficient solar cells and to integrate them into solar panels. Solarex builds standard solar panels (Unipanels®) and assembles these building blocks into larger solar-electric generators.

Solarex is equipped to develop and custom-design any type of solar-electric cell, panel or system. Solarex products will always incorporate the most advanced concepts in solar-electric conversion. In 1973 Solarex developed its terrestrial solar cell which, even by its appearance, can be easily distinguished from other solar cells.

Solarex is located in the suburbs of Washington, D.C. (20 miles from the White House) in a modern building, selected and designed to provide a research and development and production facility as well as a capability for undisturbed environmental testing of solar conversion equipment. Engineering data obtained from this test facility is being used in the design of solar-electric systems.

Chapter 1

A Little About Sunlight

Sunlight is one of those things that most of us take for granted. We know in a vague sort of way that we can get energy from the sun, but that's about the extent of our knowledge. The fact is that all energy on earth originally came from the sun. All of our hydrocarbon fuels such as coal, oil, and natural gas, were originally produced by the action of sunlight on vegetation.

In order to understand how we can use solar cells to get electrical energy from sunlight, we should know a little bit about the nature of light and the units that are used to measure it. Light is a form of electromagnetic energy—just like a radio or a television signal. The only difference is that the wavelength of light is very much shorter than that of radio waves. The color of light is determined by its wavelength. The longest light waves that we can detect visually are red in color and the shortest are violet.

ENERGY, POWER & POWER DENSITY

How do we measure the energy that reaches the earth from the sun? What units do we use to express it? From elementary physics we learn that energy is the capacity to do work. It is measured in such units as the gram-calorie, the

Table 1-1. Coversion Factors For Energy

MULTIPLY → BY ↘ / TO GET ↓	WATT-HOURS	KILOWATT-HOURS	JOULES (WATT-SECONDS)	KILOGRAM-CALORIES
WATT-HOURS	1	10^3	2.778×10^{-4}	1.163
KILOWATT-HOURS	10^{-3}	1	2.778×10^{-7}	1.163×10^{-3}
JOULES (WATT-SECONDS)	3.6×10^3	3.6×10^6	1	4.187×10^3
KILOGRAM-CALORIES	8.599×10^{-1}	8.599×10^2	2.388×10^{-5}	1

joule, or the kilowatt-hour. The ordinary household electricity meter measures electrical energy in kilowatt-hours.

An inconceivable amount of energy is radiated by the sun. Only a very small fraction of this energy—about one-half of one billionth—ever reaches the earth. This small fraction, however, is still a tremendous amount of energy. It has been estimated that every year about 745 quadrillion kilowatt-hours of energy reach the earth from the sun. It is understandable why scientists have sought for years for ways to harness this energy.

Although energy is the more fundamental concept, in practical applications we are usually more interested in *power*, which is the rate at which energy is generated or used. Power is measured in watts or kilowatts.

The amount of power that we can get from any device that harnesses sunlight depends on the amount of sunlight that it intercepts. A device that has a larger area will intercept more power from sunlight than a smaller device. For this reason we often speak of sunlight in terms of *power density*. Power density is simply the amount of power in a given area. We usually express power density in terms of milliwatts per square centimeter (mW/cm^2) or kilowatts per square meter (kW/m^2).

Historically, most of the measurements of the amount of sunlight reaching the various parts of the earth have been made by people interested in forecasting weather. Not surprisingly, they have their own unit of measurement for the purpose. It is the *langley*. One langley is equal to 11.62

Table 1-2. Conversion Factors For Power

MULTIPLY → BY ↘ TO GET ↓	MILLIWATTS	WATTS	KILOWATTS
MILLIWATTS	1	10^3	10^6
WATTS	10^{-3}	1	10^3
KILOWATTS	10^{-6}	10^{-3}	1

watt-hours per square meter. In Chapter 5, we will show how to use a more convenient unit, the number of *peak sun hours*.

In the literature about solar energy you will find these and other units used to measure energy, power, and power density. Tables 1-1, 1-2, and 1-3 show how to convert from one such unit to another. Using a small pocket calculator the conversion is very easy.

HOW MUCH ENERGY FROM SUNLIGHT?

The power density of sunlight reaching the outside of the earth's atmosphere is about 136 mW/cm^2. About one-third of

Table 1-3. Conversion Factors For Power Density

MULTIPLY → BY ↘ TO GET ↓	mW/cm^2	W/m^2	kW/m^2
mW/cm^2	1	10^{-1}	10^2
W/m^2	10	1	10^3
kW/m^2	10^{-2}	10^{-3}	1

this energy is scattered while passing through the earth's atmosphere. Thus on a clear day at noontime the power density of sunlight is about 100 mW/cm^2. This amounts to about 1 kW/m^2 or in more familiar units about 1 kilowatt per square yard.

Of course the actual power density at the surface of the earth depends on many factors. The figures quoted above are for a clear day at noontime. Early in the morning and late in the afternoon, when the sun is lower in the sky, the amount of energy received is lower, as it is on cloudy or rainy days.

The actual amount of power that we can recover from sunlight depends not only on the amount of sunlight that reaches a given area in a year, but also on the efficiency of our energy conversion device. These factors will be treated in detail in Chapter 5. We can, however, get some idea of the amount of energy that we are talking about from the fact the solar energy that is intercepted by a small tennis court would supply the energy needs of an average household. The solar energy that reaches less than one percent of the Sahara desert is more than all of the electrical energy used by all of the nations of the world.

THE UNITS OF WAVELENGTH

We mentioned earlier that light is actually a form of electromagnetic energy. The wavelength of visible light is very short as compared to that of a radio wave and therefore the usual units of measurement of wavelength, such as the

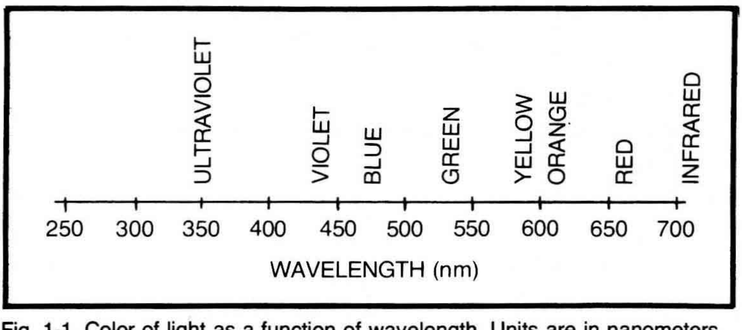

Fig. 1-1. Color of light as a function of wavelength. Units are in nanometers.

Table 1-4. Conversion Factors for Wavelengths

MULTIPLY BY → / TO GET ↓	MICRONS	ANGSTROMS	METERS	NANOMETERS
MICRONS	1	10^{-4}	10^{6}	10^{-3}
ANGSTROMS	10^{4}	1	10^{10}	10
METERS	10^{-6}	10^{-10}	1	10^{-9}
NANOMETERS	10^{3}	10^{-1}	10^{9}	1

meter, are inconveniently large. A suitable unit for the measurement of the wavelength of light is the *nanometer*. A nanometer is equal to a billionth of a meter, or in mathematical language, 10^{-9} meter. In some of the older literature on light the nanometer is called a millimicron. A micron is a millionth of a meter. Another name for the micron is micrometer.

Figure 1-1 shows the relationship between the wavelength and its color. Table 1-4 can be used to convert between nanometers and other units that are sometimes used to express the wavelength of light. Figure 1-2 shows the spectral distribution, that is, the amount of each color in ordinary daylight.

For many years, the nature of light was a subject of hot debate by physicists. At the time of Sir Isaac Newton, about

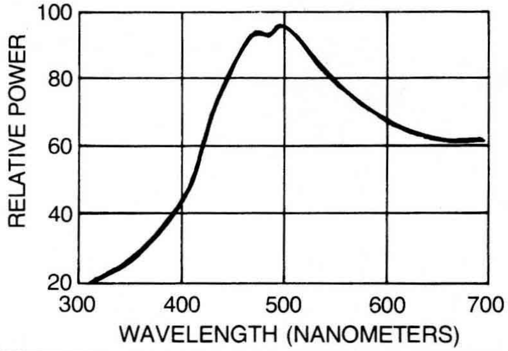

Fig. 1-2. Spectral distribution of daylight. Units are in nanometers.

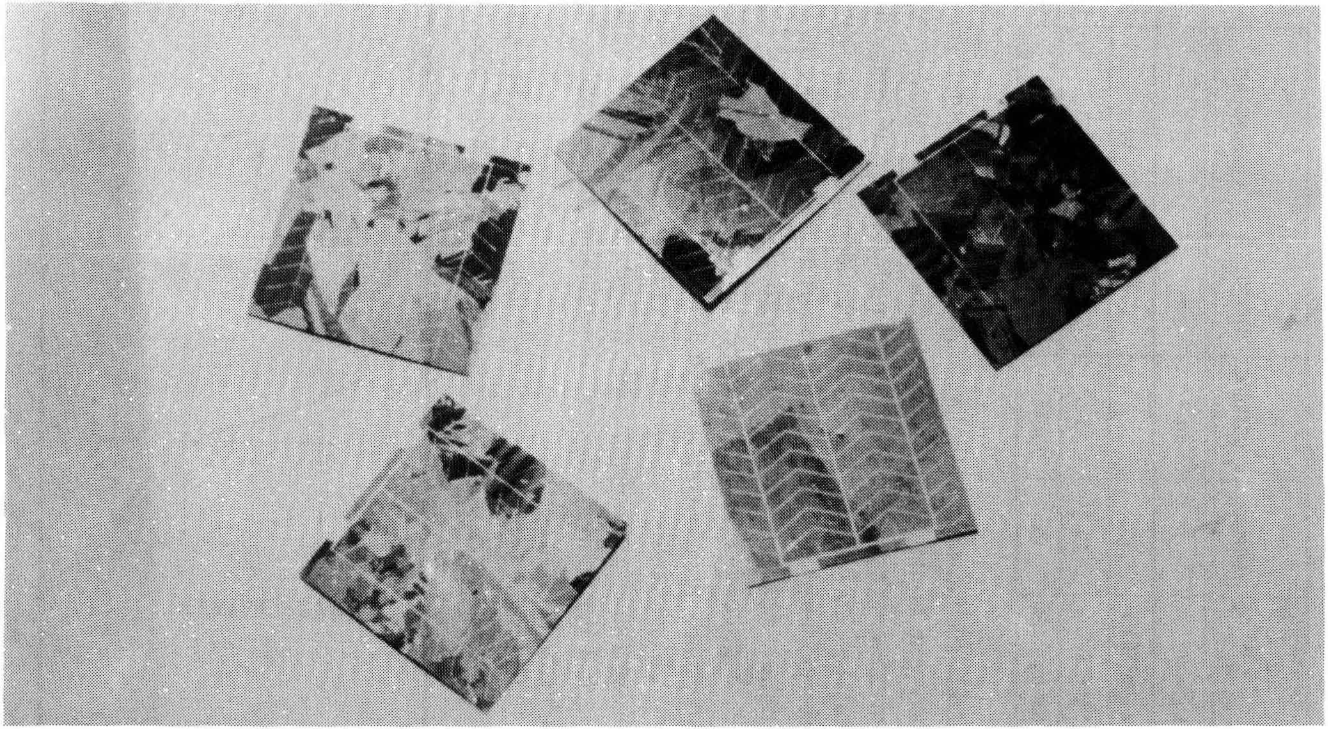

Fig. 1-3. The single-crystal semiconductor-grade silicon from which most solar cells are made is extremely expensive. Cells fabricated from relatively impure semicrystalline silicon, such as shown here, offer great potential for cutting solar-cell prices.