

SRI Y.N.COLLEGE (AUTONOMOUS)-NARSAPUR
DEPARTMENT OF PHYSICS

2016-2017

STUDENT STUDY PROJECTS

SRI Y N COLLEGE (AUTONOMOUS) NARSAPUR
DEPARTMENT OF PHYSICS

STUDY PROJECTS

Submitted to

DEPARTMENT OF PHYSICS

OPTICAL FIBRE NETWORK

(2016-2017)

PROJECT DONE BY

- | | |
|----------------|-------------------|
| 1. Hymavathi K | – III MPE-EM – 10 |
| 2. Divya Bokka | III MPCs-EM – 35 |
| 3. Siva Ketha | III MPC – EM –15 |

Under the guidance of :

1. Dr A P V Appa Rao
2. Sri J Rama Mohan
3. Dr L Malleswara Rao
4. Sri P Ramakrishna Rao

DEVELOPMENT OF COMMUNICATIONS IN NARSAPUR THROUGH OPTICAL FIBRE NETWORK

INTRODUCTION:

FIBRE OPTICS is a technology related to transportation of Optical Energy (transmission of light) using Optical fibres, their emission and detection.

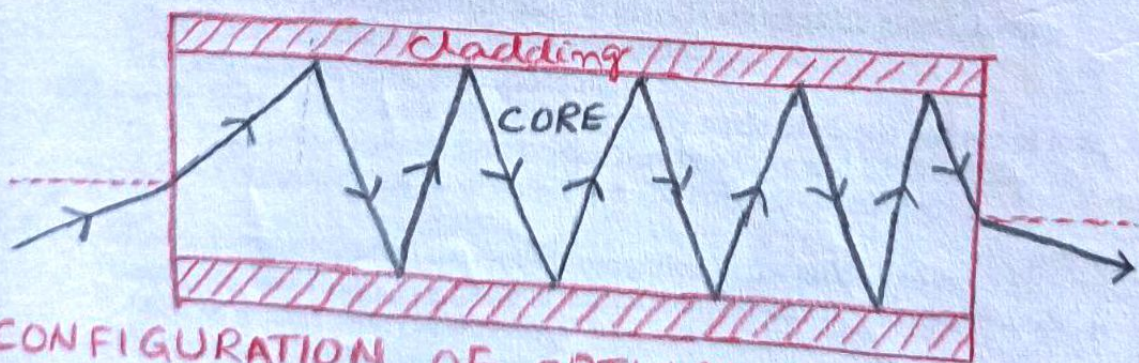
The optical fibre communication system is to transfer information from source to distant user. The development of Laser and the Optical fibre has brought about a revolution in communication system, because of the low loss and high band-width, they are ideally suited for carrying voice, data and video signals in a high information capacity system.

PRINCIPLE:

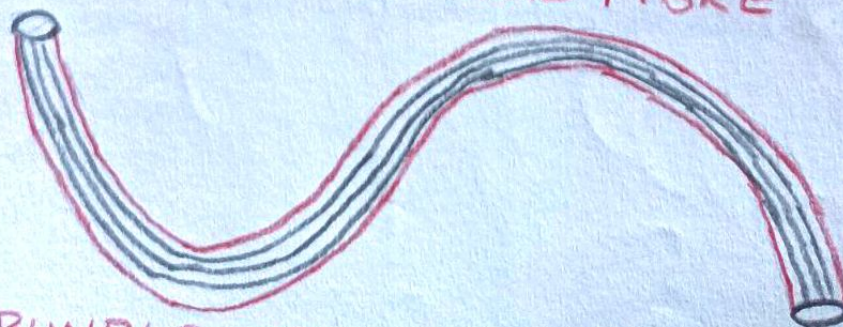
The principle behind the transmission of light waves in an optical fibre is **Total Internal Reflection**.

STRUCTURE OF OPTICAL FIBRES:

An Optical fibre is a dielectric wave guide and is normally cylindrical in form. It consists of a bundle of very thin individual fibres. It consists of an inner glass cylinder of high refractive index $\mu(1)$ which is known as **core**. The core is surrounded by a cylindrical shell of glass or plastic of low refractive index $\mu(2)$ called **cladding**, which is used to keep the light waves within the core by total internal reflections. The thickness of the core is nearly $50\mu\text{m}$ and that of cladding is 100 to $200\mu\text{m}$. The overall thickness of an Optical fibre is nearly $150\mu\text{m}$ (0.00015 cm). An Optical cable is small in size, weight and flexibility. A beam entering at one end can be transmitted to other end even though the fibre is curved as shown in figure.



CONFIGURATION OF OPTICAL FIBRE



BUNDLE OF GLASS FIBRE

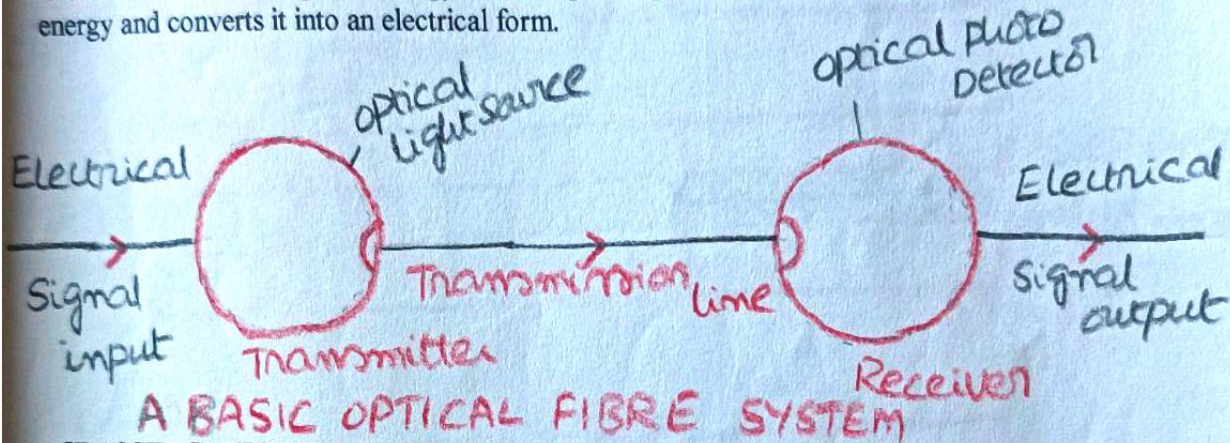
FIBRE OPTIC MATERIALS:

Optical fibres are made up of materials like silica and plastic. It has the following properties.

- I) Efficient guide for the light waves.
- II) Low scattering cross section.
- III) The absorption, attenuation and dispersion of Optical Energy are low.

FIBRE OPTICAL SYSTEM:

It consists of a transmitter which transforms an electrical signal (information signal) to be transmitted into Optical signal i.e. optical light source. The optical fibre transmission line is the conductor of Optical energy. The **Optical photo detector** detects the optical energy and converts it into an electrical form.



CLASSIFICATION OF OPTICAL FIBRES:

The optical fibres are classified into three major categories based on (a) material (b) the number of modes (c) refractive index profile.

(a) **Material:** based on the material classified as

- (1) **Glass fibre:** Common material used in glass is silica (oxide glass), having slight refractive index for the core and cladding.
Ex. GeO_2 — SiO_2 core, SiO_2 cladding.
- (2) **Plastic fibre:** The Plastic fibres are typically made of plastic and are of low Cost. High refractive index difference between Core and Cladding.
Ex. A Poly methyl methacrylate-Core; Co Polymer- Cladding.

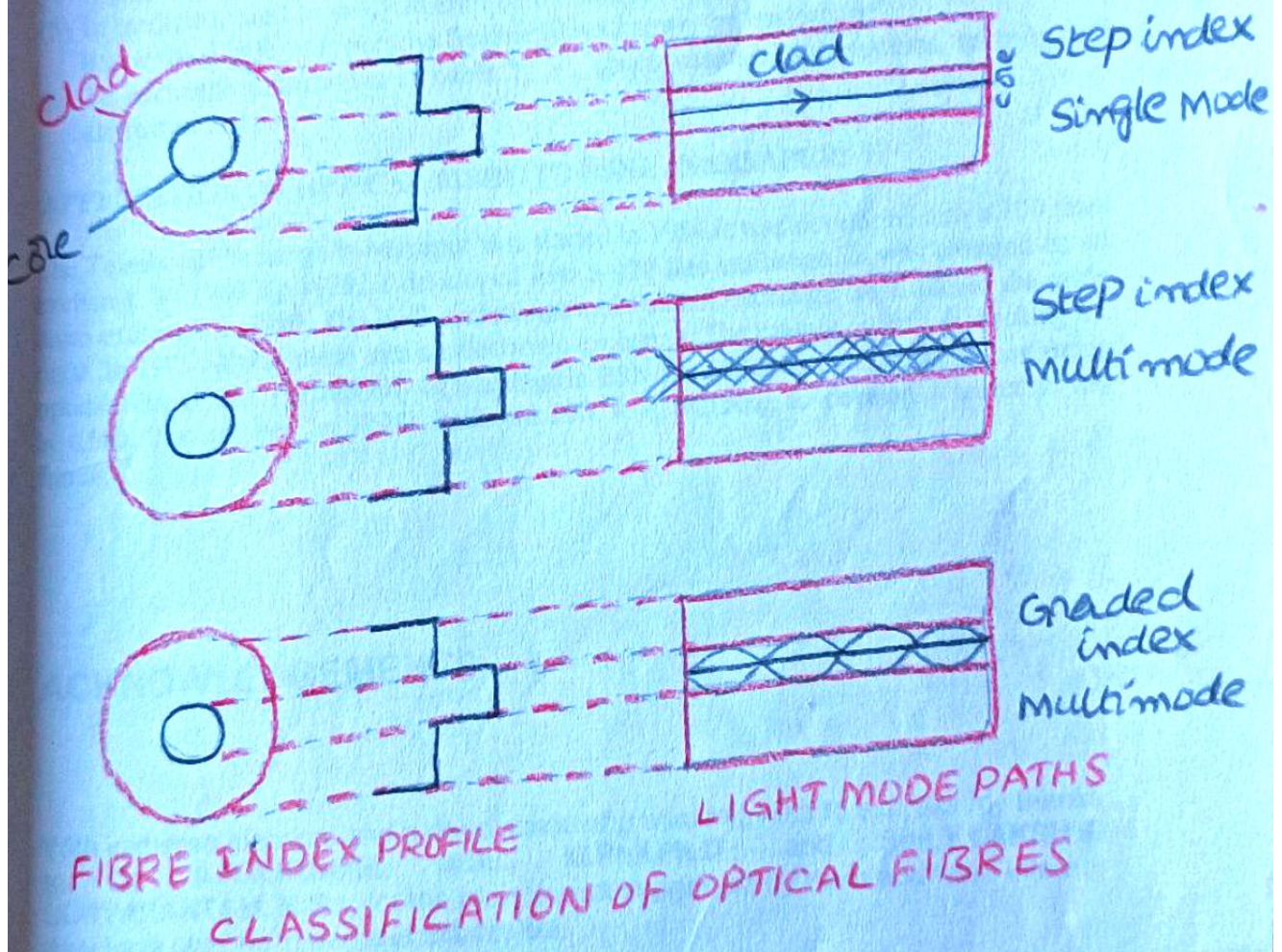
(b) **No of Modes:** Depending upon the types propagation in the guide into two.

- (1) **Single-mode:** If only one mode is transmitted through it, it is single mode. It must be excited with Laser Diodes
- (2) **Multimode:** If more than one mode is transmitted through optical fibre, it is Multimode fibre. The light can be launched using a light emitted diode (LED) Source.

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PREPARATION OF OPTICAL FIBRES:

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(2) **Crucible-Crucible method:** The core and cladding materials are taken in inner and Outer tubes of double crucible. The melts of the core and cladding are allowed to flow through the orifice and allowed to cool to room temperature.

USES:

- (1) Large number of telephone signals nearly 15000 can be passed in a particular time whereas 48 signals only in copper cables.
- (2) It have immunity to adverse temperature, moisture and chemical reactions.
- (3) The cost of cables is low compared to metal cables.
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- (5) In medicine, used to study interior of the lungs, to study tissues and blood vessels far below the skin for this purpose flexible fibres known as 'endoscope'.
- (6) To exchange information in cable T. V., space vehicles, sub marines, security and alarm systems etc.

APPLICATION OF OPTICAL FIBRE TO BSNL , NARSAPUR:

The Telephone Exchange in Narsapur was started in 1954. It was developed into a 100 lines exchange by 1960. By 1978, it developed into a 400 line exchange. It was changed as an Auto exchange in 1990. The NSP exchange and Palakol exchange were allotted the same code. In 1995, it was made into an electronic exchange. The present system is working on optical fibre cable. The capacity of landlines in BSNL is 600 and the number of consumes is 4,500. The number of BSNL cells are 500. It is planning to develop Internet in the future.

ACKNOWLEDGEMENTS

With immense pleasure and a deep sense of gratitude, I wish to express my thanks to **Dr. A.R.S.KUMAR, M.Sc., M.Phil, Ph.D.,** and **Smt.Y.LAKSHMI SURYAKANTAM, M.Sc.,** for the project work suggested by them and keen interest they have evinced throughout this project.

We also express our thankfulness to **Lt. Cdr. K. Lakshminarayana Rao, M.Sc., M.Phil.,** Head of the department of Physics, Sri Y.N.College. Narsapur, for providing all the facilities in the department.

We are thankful to **The Authority of BSNL, Narsapur** for their co-operation in collecting the data and necessary information.

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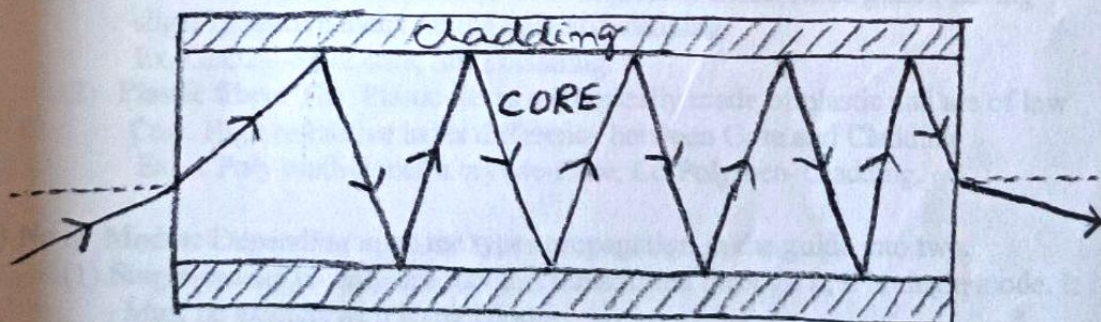
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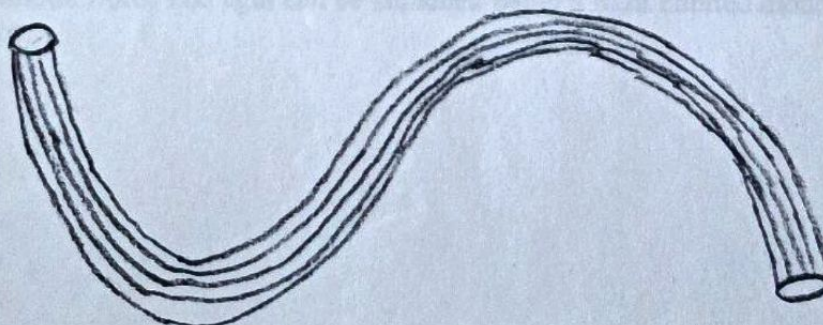
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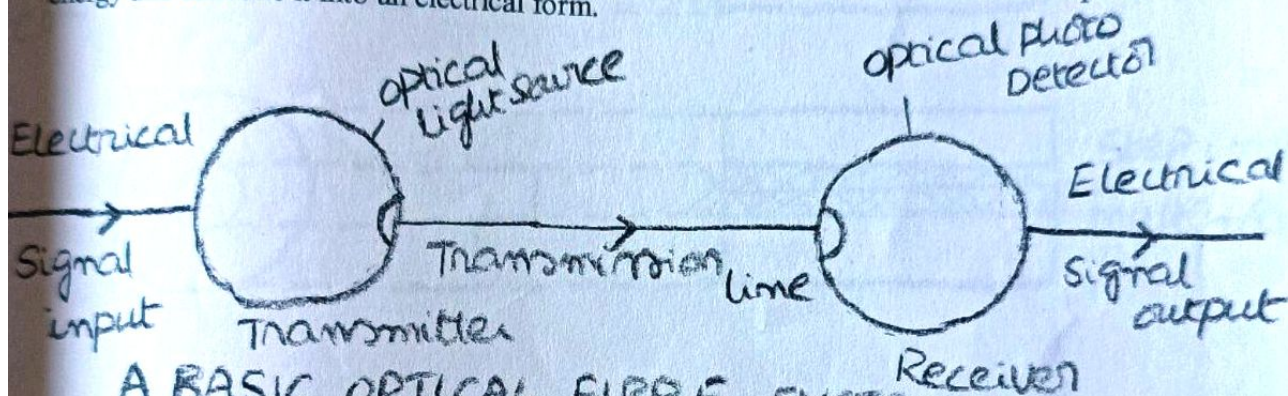
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A BASIC OPTICAL FIBRE SYSTEM

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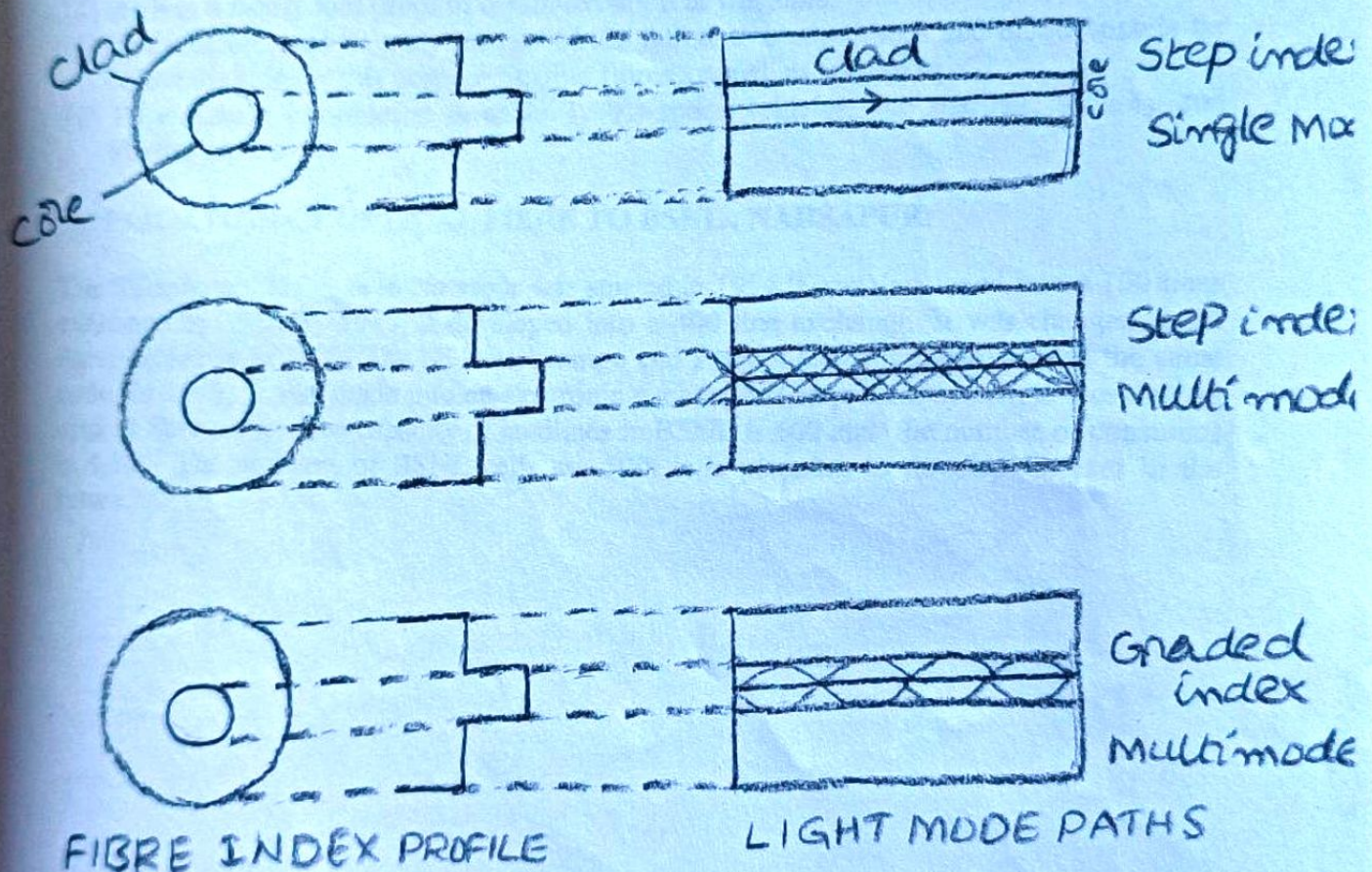
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**SRI Y N COLLEGE (AUTONOMOUS) NARSAPUR
DEPARTMENT OF PHYSICS**

STUDENT MINOR REASEARCH PROJECT

Submitted to

DEPARTMENT OF PHYSICS

CLAP SWITCH

(2016-2017)

PROJECT DONE BY

- | | |
|------------------------|-------------------|
| 1. T Adi Lakshmi | – III MPC-TM – 1 |
| 2. Kopparthi Naveena | III MPE – 8 |
| 3. Devi Bramarambica R | III MPCs – EM – 2 |

Under the guidance of :

1. Dr A P V Appa Rao
2. Sri J Rama Mohan
3. Dr L Malleswara Rao
4. Sri P Ramakrishna Rao

INTRODUCTION:

This is a circuit that can switch on and off a light, a fan or a radio or a tv etc by the sound of a clap.

Now enjoy the action which is at your claps. It is a very interesting and thrilling project for the young hobbyists, simply clap your hands and lamp will starts glow. Next clap again the same lamp will go off automatically. The example of action given here is the controlling of a bulb by clapping of hands. However you may use any electric or electronic device instead of the bulb. The device may be a radio, stereo, tape recorder or a small motor, to open a door etc as per your choice.

WORKING:

The sound of clap is received by a small microphone that is biased by resistor R_1 in the circuit. The signal is further amplified by transistors Q_1, Q_2, Q_3 . The relay contact is connected to the power line and hence turns on/off any electrical device connected at output socket.



PARTS LIST

RESISTORS:

R1	15K Ω
R2,5,12	2M2
R3	270K Ω
R4	3K3
R6,10	27K Ω
R7,11	1K5
R8,9	10K Ω
R13	2K2

CAPACITORS:

C1	10KPF
C2,3	47KPF Disc
C4	1000 μ F/16V

SEMICONDUCTORS:

Q1,2,3,4	BC 149
D1	IN 4002
D2,3,4,5	IN 4148

MISC:

12V/300 mA Transformer

Condensor Mic

Relay 12V SINGLE CHARGE
OVER RELAX

SRI Y N COLLEGE

DEPARTMENT OF

PHYSICS

PROJECT

On

SOLAR CELL

Submitted by

B.V.NAGARAJU(11504036)

P.DURGA PRASAD(11504039)

K.S.S.SANDEEP(11504040)

B.D.V.V.SATYANARAYANA(11504042)

III B.Sc. M.P.E

1 Introduction

In the current energy crisis, the search for a viable alternative to hydrocarbons has taken many paths: nuclear, wind, solar, etc. Solar cells provide an attractive form of limitless alternative energy. The placement of solar cells can be unobtrusive and provide not only a source of thermal energy, but electricity. However, the development and implementation of effective photovoltaic cells is hindered by two primary components: cost and efficiency.

Research into cheaper and more efficient solar cells has been underway for several decades. From the development of thin-film solar cells with efficiencies greater than 10% in the 1970s to the most recent developments in new photovoltaic materials achieving greater than 24% efficiency (see Figure 1) [1]. Unfortunately, the cost of electricity from current solar cells is about one order of magnitude higher than commercial prices. However, several of the recent developments hold a promising future for the field [1]. We begin by looking at the development of solar cells in general, and the new technologies available.

2 Solar Cell Technology

The basic mechanism behind a solar cell is based on the photoelectric effect and semiconductor physics. A photon with energy greater than the bandgap energy ($h\nu > E_{gap}$) incident on a semiconductor can excite electrons from the valence band to the conduction band, allowing for current flow. The maximum current density is then given by the flux of photons with this energy. Excess energy is lost to thermalization ($h\nu - E_{gap}$). The excitation of the electron to the conduction

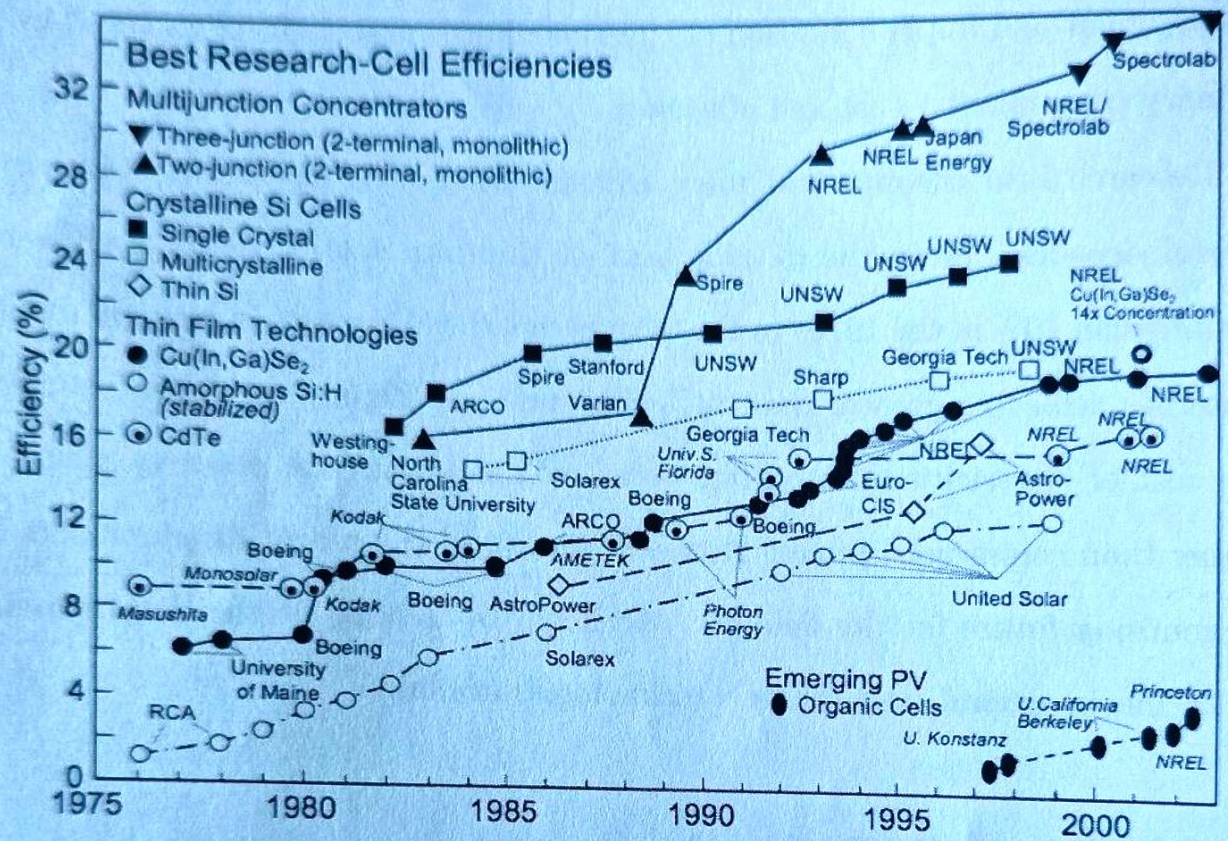


Figure 1: Photovoltaic efficiencies from various materials over the years [1].

band results in a hole in the valence band [2]. In the case of organic polymer solar cells, the electron and its corresponding hole exist in a bound state due to Coulomb attraction. This state, known as an exciton, has a lower energy than an unbound electron and hole [2].

In its simplest form, a solar cell is a large-area p-n junction. Energy from incident light creates the electron-hole pairs (or excitons in the case of organic semiconductors) described above. The electron-hole pairs separate at the junction, with electrons (holes) diffusing across the depletion zone to the p-type (n-type) region, where they become thermally free and generate a current [3]. This simple, but effective model illustrates two important factors in the production of solar cells regarding their efficiency and cost.

It is obvious that the current generated from light incident on a p-n junction is directly dependent on both the mobility of the carriers in the material and the exposed surface area of the junction. For these reasons, semiconductor materials with greater charge mobility and costs low enough to produce at a large scale are needed.

2.1 Silicon: Crystalline and Amorphous [4]

More than 80% of solar cells currently produced are crystalline silicon solar cells. Nearly all of the other 20% are developed as amorphous silicon solar cells [4]. Silicon wafers have long been the primary base for assembly.

Crystalline silicon solar cells at the commercial level have achieved efficiencies of as much as 16%, whereas experimental developments have achieved efficiencies of more than 24% [4]. These solar cells have proven to be robust in their stability

and reliability, even when exposed to harsh conditions over several years.

However, the use of crystalline silicon has several financial disadvantages. The complex processing steps and need for large amounts of high purity silicon stock have driven the cost of these solar cells up [4]. For wafer-based cells, the wafer sizes are limited, and it therefore becomes necessary for them to be externally assembled and connected to obtain larger surface areas. Two plans for improving the cost/efficiency of wafer-based solar cells are the addition of an epitaxial layer or doped amorphous silicon on the wafer surface [4].

The deposition of an high-quality epitaxial layer with appropriate uniformity has been shown to result in efficiencies greater than 19%, but has been difficult and costly to implement commercially [4]. However, the deposition of the doped amorphous silicon for the purpose of forming a heterojunction has produced similar efficiencies, while also simplifying the processing [4].

Recent interest has shifted from wafer-based silicon solar cells to thin-film crystalline silicon. The film thickness are typically $< 10\mu m$ [4]. Low temperature depositions from the gas phase allow for the use of cheap substrates (glass, or aluminum for example). With the addition of hydrogen in the growing crystalline layer, efficient grain-boundary passivation can be achieved giving desired layer properties with grain sizes $< 1\mu m$ [4]. The current method of choice for such depositions is plasma-enhanced chemical vapor deposition (PECVD), which can allow for deposition temperatures as low as 220 °C. Unfortunately, the best efficiencies achieved are just below 10% [4].

Crystalline solar cells are not the only option. In the 1970s, hydrogenated amorphous silicon (a-Si:H) was introduced as a potential material for semiconductor devices [4]. Since then, it has become the first thin-film material to enter

large-scale production for solar cells. The higher visible spectrum optical absorption over crystalline silicon allows for film thicknesses much less than $1\mu m$ [4].

a-Si:H solar cells are ordinarily created with a p-i-n structure in order to reduce recombination losses [4]. Deposition is usually done via PECVD onto various substrates. A common substrate used is TCO coated glass (e.g. SnO_2), with the TCO acting as the front contact [4]. Opaque substrates (stainless steel or polymer), however, are available in flexible foils, making roll-to-roll deposition processes possible (a fast production method easily implemented commercially). However, deposition costs and times ($\sim 1\text{\AA}/hour$) for roll-to-roll deposition and TCO substrate have kept amorphous silicon cells from being significantly more cost effective than crystalline silicon solar cells at the current time. Furthermore, a-Si:H solar cells have only achieved an efficiency of 13% in the laboratory and 8% commercially and suffer from light-induced degradation (Staebler-Wronski effect) [4]. This degradation reduces efficiency after ~ 1000 hours of operation [4].

Currently, a-Si:H are one of the best candidates for the future of solar cells, due largely to their ability to be produced on cheaper substrates and integrated onto roofs and structures. While low in efficiency compared to crystalline silicon solar cells and stability issues, it is likely that production cost for a-Si:H solar cells will continue to drop in the future [4].

2.2 Other Thin-film Materials: CIS Related, CdTe and Dye Sensitized

Copper-Indium:Diselenide (CIS) and Copper-Indium:Gallium-Diselenide (CIGS) are direct-gap polycrystalline p-type semiconductors with high optical absorption

[4]. That is, the minimum of the conduction band has the same wave-vector as the maximum of the valence band [4]. CIS and CIGS are used in heterojunctions with n-type layers (commonly CdS or ZnO) [5].

CIS and CIGS have a remarkably high efficiency for polycrystalline thin films, at 18.8% in the laboratory. The high efficiency is due to the effective bandgap between 1.1 to 1.2 eV [4]. The addition of Gallium in CIGS increases the bandgap and the performance tune by increasing the open-circuit voltage.

CIS and CIGS solar cells also show good stability and reliability, except in considerable heat and humidity. While commercial production of these solar cells is projected to be significantly cheaper than for wafer-based crystalline silicon solar cells, it is very likely that full scale production will experience difficulties with the availability and price of Indium [4].

Another thin-film material similar to CIS and CIGS is CdTe. CdTe also has a direct bandgap and high optical absorption, but a bandgap energy of 1.45 eV [4]. This results in higher current densities and higher open-circuit voltages than with CIS/CIGS. Typical efficiencies are 16% in the laboratory and 9% commercially [4]. Another benefit of CdTe solar cells is the significant enhancement of carrier multiplication from CdTe nanocrystals. Carrier multiplication is the process by which inelastic scattering of charge carriers and valence electrons creates additional electron-hole pairs (charge carriers). With sufficient enough carrier multiplication, energy lost by photons with energy in excess of the bandgap due to thermalization could be collected [6]. Nanocrystals in photovoltaics is discussed further in the following section.

CdTe is a binary compound, and thus easier to produce solar cells with than CIS/CIGS. Typically, a heterojunction is created on a TCO coated glass substrate

using n-type CdS and p-type CdTe.

Obtaining a uniform deposition of CdS is a critical issue in the production of both CIS/CIGS and CdTe solar cells, particularly since stability and efficiency are dependent on the n-p junction. However, a greater hurdle is the use the Cadmium, particularly in CdTe solar cells. While CdTe and CdS are stable, their production from the hazardous material Cd introduces hazards that require strict regulation [4].

The final thin-film we will briefly discuss are dye-sensitized photovoltaic solar cells. Dye-sensitized solar cells were first designed by Michael Gratzel of Ecole polytechnique federale de Lausanne and are unique in that conduction involves only injected electrons, not excitons or correlated electron-hole pairs [7]. Such solar cells have a multilayer structure that separate the processes of light absorption and charge carrier transport, reducing recombination (see Figure 2.2) [8]. Electrolytic dye molecules on a thin surface of gold film absorb incident photons. Electrons from the dye are excited to the conduction band of the gold film. The gold film is deposited onto a TiO_2 layer. The gold- TiO_2 junction creates a Schottky barrier. The excited electrons from the dye must have enough energy to penetrate the Schottky barrier to the conduction band of the TiO_2 , generating current through the device [8].

Dye-sensitized solar cells currently achieve an efficiency of about 10% in the laboratory [8]. However, the electrolytic dye can lead to stability issues, particularly outside of prescribed temperature ranges, and additional costs for integrating into series connected systems [4, 8].

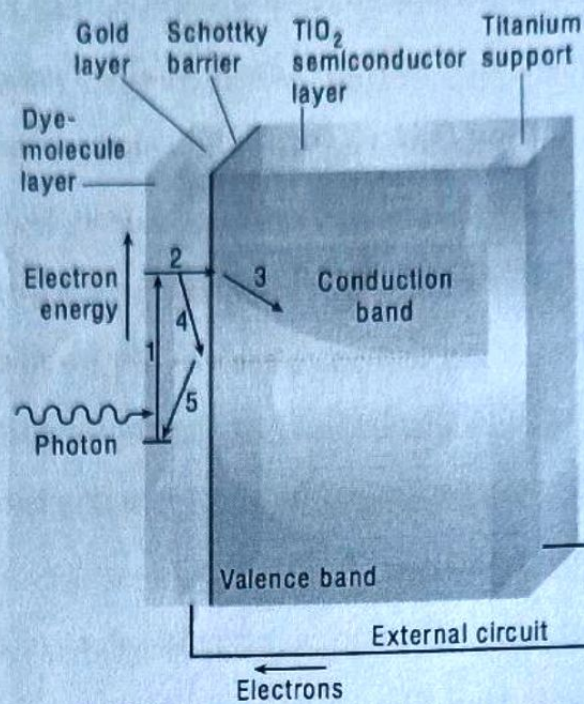


Figure 2: Dye-sensitized solar cell schematic [8]

2.3 Organic Polymers

Inorganic materials are not the only option available for solar cells, however. Around 20 years ago, it was discovered that organic materials could be used in making photovoltaics. However, it was not until the 1990s that a conducting organic polymer solar cells were shown to have an efficiency of 2.9% [2]. Recently developments in the science have resulted in laboratory results of organic solar cells reaching efficiencies as high as 5% [2].

Organic photovoltaics are based on the illumination of a donor and acceptor species. This illumination leads to the separation of excitons, much like in inorganic semiconductors. Organic solar cells are constructed out of various organic polymers, usually embedded with fullerene (acting as the acceptor) [2]. A current

polymer being researched is poly 3-hexylthiophene (P3HT) [9].

However, the details of their performance introduce issues. One issue is the correlation between the separation of the bound electron-hole exciton, the primary difference between organic and inorganic solar cells [2]. Excitons experience stronger correlation in organic polymers. The bound state formed by the electron-hole pair makes the charge separation a consideration in efficiencies [2]. Furthermore, there is much research left to be done in the construction of these polymers so as to broaden the light harvesting in the spectrum of visible light, and to deal with nonlinear optical properties [2].

Despite its infancy and low efficiencies, organic solar cells offer a very attractive alternative to inorganic thin-films. The organic polymers used in production allow for solar cells to be made cheaply while still being lightweight and flexible. Additionally, it is easy to extend to large-area modules [2].

2.4 Nano-Scale Materials

Interest has been taken in the use of nanocrystals as an option for effective and inexpensive solar cells. It is believed that the size and shape control of the nanocrystals will allow for the customization of bandgap through absorption of light across the whole spectrum. Furthermore, the 3D confinement leads to greater impact ionization and results in multiple charge carrier creation from a single photon [10]. The confinement increases the density of states along the band edge in a given dimension [11]. With this property, and control of the inter-crystal spacing, the nanocrystals can be thought of as artificial atoms that allow for the tuning of discrete electronic states via size regulation [12]. This control allows for the spectrum

of absorption to be tuned at will [2].

Nanocrystalline solar cells consist of large arrays of quantum dots. Current work with PbSe quantum dot solar cell arrays has shown the generation of two to three charge carriers (commonly excitons due to the use of organic polymers with nano-scale photovoltaics) per absorbed photon [13]. Such arrays are cheaper to manufacture than other photovoltaic options because of the ability to process them from solution. However, the efficiency is only around 2.5% compared to the theoretical efficiency of 44% [13]. Harnessing the multiple exciton generation will doubtlessly boost the efficiency. Additionally, the transport of electrons across the array to the circuit electrodes is hindered by the organic chemical coatings used to maintain the stability of the quantum dots [13].

While the intrinsic carrier mobility of the organic coatings reduce the efficiency of nano-scale solar cells, hybrid materials show a promising future as cheap alternatives to conventional inorganic solar cells. One such option is hybrid nanorod-polymer solar cells (see Figure 2.3).

Solution phase synthesis at low temperature (below 300°C) of CdSe nanocrystals allows for the formation of nanorods [9]. The inorganic rods can be combined with a conjugated polymer, P3HT. This gives a high surface area charge transfer junction. CdSe acts as the electron transport medium, whereas the P3HT acts as the hole transport medium. P3HT has the highest field effect hole mobility currently found in a polymer, at $0.1\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ [9]. The absorption spectrum of CdSe and P3HT complement each other, giving a fairly broad visible range of absorption.

P3HT is particularly attractive in that it can be easily cast from a room-temperature solution [9]. Unfortunately, the surface chemistry behind embedding

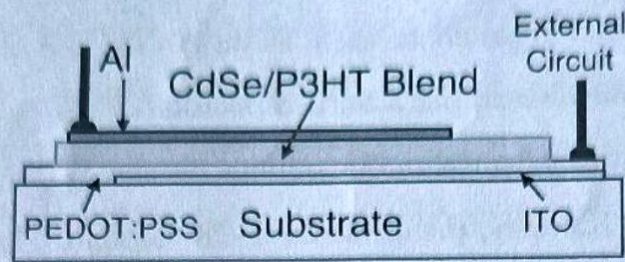


Figure 3: Hybrid nanorod-polymer solar cell schematic [9]

CdSe nano-rods in the P3HT film is very complex due to the nanocrystals limiting the solubility of the polymer. Once again, the polymer also inhibits electron hopping among the crystals and results in a low efficiency (currently reported at 1.7%, with an open-circuit voltage of 0.7 V) [9]. However, altering the aspect ratio of the rods can help in tailoring the length scale and direction of the electron transport. Through further investigation in this tailoring, it is hoped that higher efficiencies can be reached, thus providing a cheap and effective solar cell [9].

3 Conclusion

The sun delivers more energy to the Earth in one hour than is used in a year from all currently available sources, however only 0.1% of the world's energy is derived from it [2]. There are several options available in the production of solar cells. However, it seems unlikely that photovoltaic technology carry the bulk of the world's energy

needs in the near future. While thin-films show a great deal of promise, the 24% efficiencies of silicon solar cells has yet to be bested [1]. Unfortunately, silicon solar cell production remain too costly at the commercial level.

Nanocrystalline hybrid arrays show a promising future for cheaper and more efficient solar cells, despite the infancy of the field. The DOE remains optimistic regarding the future of nano-scale materials in photovoltaics. While organic polymers offer a similar (or better) option in terms of cost, nanocrystalline quantum dots provide a tunable absorption spectrum and they promise harnessing of multiple exciton generation [2]. Fabrication at the nano-scale provides a remarkable increase in the precision and level of control that can be obtained over solar cell development. This ability to experiment with, understand, and thus simulate the behaviour of photovoltaics at such a fundamental level bring the field into a new and lucrative realm [2].

References

- [1] T. Surek. Progress in u.s. photovoltaics: Looking back 30 years and looking ahead 20. National Renewable Energy Laboratory.
- [2] DOE Office of Science. *Basic Research Needs for Solar Energy Utilization*, April 2005, available: <http://www.sc.doe.gov/bes/reports/list.html>.
- [3] John E. Ayers. *Digital Integrated Circuits: Analysis and Design*. CRC Press, 2003.
- [4] A. Shah et al. The case for thin films. *Science*, 285:692, 1999.
- [5] T.J. Anderson, S.S. Li, O.D. Crisalle, and V. Craciun. Fundamental materials research and advanced process development for thin-film cis-based photovoltaics. Technical Report NREL/SR-420-40568, National Renewable Energy Laboratory, 2006.
- [6] G. Nair and M. Bawendi. Carrier multiplication yields in cdse and cdte nanocrystals by transient photoluminescence. *arXiv:0708.3866v1*, 2007.
- [7] J.S. Agnaldo, J.C. Cressoni, and G.M. Viswanathan. Universal photocurrent-voltage characteristics of dye sensitized nanocrystalline tio2 photoelectrochemical cells. *arXiv:0801.4334v1*, 2008.
- [8] M. Gratzel. Applied physics solar cells to dye for. *Nature*, 421:586, 2003.
- [9] W. U. Huynh et al. Hybrid nanorod-polymer solar cells. *Science*, 295:2425, 2002.
- [10] J.S. de Sousa, J.A.K. Freire, and G.A. Farias. Exciton escape in cdse core-shell quantum dots: Implications for the development of nanocrystal solar cells. *Physical Review B*, 76(155317), 2007.
- [11] V.I. Klimov et al. Optical gain and stimulated emission in nanocrystal quantum dots. *Science*, 290:314, 2000.
- [12] D. Yu, C. Wang, and P. Guyot-Sionnest. n-type conducting cdse nanocrystal solids. *Science*, 300:1279, 2003.
- [13] Robert Service. Can the upstarts top silicon. *Science*, 319:718, 2008.