CHAPTER 1

INTRODUCTION

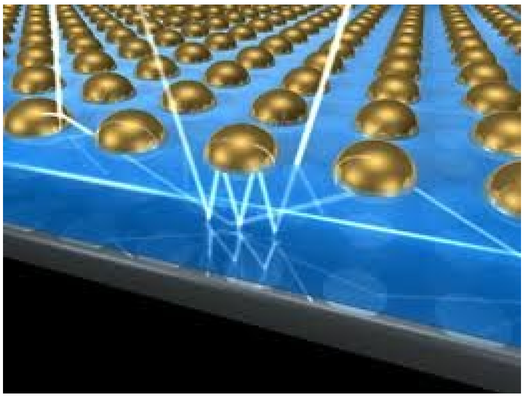

Fig 1.1 Plasmonic Solar Cells

1.1 PLASMONIC SOLAR CELLS: BASIC CONCEPT

Plasmonic Solar Cells (PSC) are known as photovoltaic devices. They have great potential in driving the cost of solar power down. In order for the solar cell (SC) technology to be a viable energy source to compete with fossil fuels, the price needs to be reduced by 2-5x. Approximately 90% of the market for solar cells use silicon wafers. These wafers are typically around 200-300µm thick and constitute about 40% of the cost. Plasmonic solar cells are a type of thin-film solar cells which are typically 1-2µm thick. They also use substrates which are cheaper than silicon, such as glass, plastic or steel. The biggest problem for thin film solar cells is that they don't absorb as much light as the current solar cells. Methods for trapping light on the surface, or in the solar cell are crucial in order to make thin film solar cells viable. An important point about plasmonic solar cells is that they are applicable to any kind of solar cell. This includes the standard silicon or newer thin-film types.

Current solar cells have ways of trapping light. However, their method is to create pyramids on the surface which have dimensions bigger than most thin film solar cells. Making the surface of the substrate rough (typically by growing SnO_2 or ZnO on surface) with dimensions of the order of the incoming wavelengths and depositing the solar cell on top has been explored. This method increases the photocurrent, but the thin film solar cells would then have poor material quality. Other methods have been explored for increasing the absorption of light in thin film solar cells. One method which has been explored over the past few years is to scatter light using metal nanoparticles excited at their surface plasmon resonance. Different approaches using these metal nanoparticles and the basic principles which govern how the scattering/absorption is increased will be the focus of the following information along with a detailed description of polymeric solar cells, their design and application of plasma in designing and fabrication.

There have been quite a few pioneers working with plasmonic solar cells. One of the main focuses has been on improving the thin film solar cells through the use of metal nanoparticles distributed on the surface. It has been found that the Raman scattering can be increased by order of magnitude when using metal nanoparticles. The increased Raman scattering provides more photons to become available to excite surface plasmons which cause electrons to be excited and travel through the thin film solar cell to create a current.

The promising field of plasmonics has yielded methods for guiding and localizing light at the nanoscale. Now focus of plasmonics research is turning to photovoltaics, where design approaches based on plasmonics can be used to improve absorption in photovoltaic devices, permitting a considerable reduction in the physical thickness of solar photovoltaic absorber layers, and yielding new options for solar cell design. Due to a combination of the resonant plasmonic properties of metallic nanoparticles with thin-film photovoltaic technology, a new generation of plasmonic solar cell has evolved with similar performance to silicon cells but at potentially a fraction of the cost. Today, plasmonic solar cells are emerging as promising candidates amongst many solar energy technologies spurring continuing research to improve device performance.
This research report also devotes a section to the technical aspects of Photovoltaic Solar Cells systems including their history as well as mechanism, general operation principles and the new innovations in architecture design of Plasmonic Solar Cells which have opened up new markets for solar power systems. These are further explained in the efficient design choices of various configurations and new ideas contributed in this field.

1.2 DESIGN AND BASIC PRINCIPLE

The design for plasmonic solar cells varies depending on the method being used to trap and scatter light across the surface and through the material. The basic principles for the functioning of plasmonic solar cells include scattering and absorption of light due to the deposition of metal nanoparticles. Silicon does not absorb light very well. For this reason, more light needs to be scattered across the surface in order to increase the absorption. It has been found that metal nanoparticles help to scatter the incoming light across the surface of the silicon substrate. The equations that govern the scattering and absorption of light can be shown as:

$$C_{scat} = \frac{1}{6\pi}\left(\frac{2\pi}{\lambda}\right)^4 |\alpha|^2$$

This shows the scattering of light for particles which have diameters below the wavelength of light. Many of the plasmonic solar cells use nanoparticles to enhance the scattering of light. These nanoparticles take the shape of spheres, and therefore the surface plasmon resonance frequency for spheres is desirable.

Wavelength Dependence

Surface plasmon resonance mainly depends on the density of free electrons in the particle. The order of densities of electrons for different metals is shown below along with the type of light which corresponds to the resonance.

- Aluminum - Ultra-violet
- Silver - Ultra-violet
- Gold - Visible
- Copper - Visible

If the dielectric constant for the embedding medium is varied, the resonant frequency can be shifted. Higher indexes of refraction will lead to a longer wavelength frequency.

1.2.1 Metal Nanoparticle Plasmonic Solar Cells

Fig 1.2 PSC using metal nanoparticles

A common design is to deposit metal nanoparticles on the top surface of the thin film solar cell. When light hits these metal nanoparticles at their surface plasmon resonance, the light is scattered in many different directions. This allows light to travel along the solar cell and bounce between the substrate and the nanoparticles enabling the solar cell to absorb more light. The metal nanoparticles are deposited at a distance from the substrate in order to trap the light between the substrate and the particles. The particles are embedded in a material on top of the substrate. The material is typically a dielectric, such as silicon or silicon nitride. When performing experiment and simulations on the amount of light scattered into the substrate due to the distance between the particle and substrate, air is used as the embedding material as a reference. It has been found that the amount of light radiated into the substrate decreases with distance from the substrate. This means that nanoparticles on the surface are desirable for radiating light into the substrate, but if there is no distance between the particle and substrate, then the light is not trapped, rather it escapes.

1.2.2 Metal Film Plasmonic Solar Cell

Other methods utilizing surface plasmons for harvesting solar energy are available. Such type of structure is to have a thin film of silicon and a thin layer of metal deposited on the lower surface. The light will travel through the silicon and generate surface plasmons on the interface of the silicon and metal. This generates electric fields inside of the silicon since electric fields do not travel very far into metals. If the electric field is strong enough, electrons can be moved and collected to produce a photocurrent. The thin film of metal in this design must have nanometer sized grooves which act as waveguides for the incoming light in order to excite as many photons in the silicon thin film as possible.

Fig 1.3 Thin film solar cell and typical solar cell

When a photon is excited in the substrate of a SC, an electron and hole are separated. Once the electrons and holes are separated, they will want to recombine since they are of opposite charge. If the electrons can be collected prior to this happening then the SC is pretty efficient. The way to collect the electrons quickly would be to make the conducting material very thin. If the surface is made very thin, there will be less light absorbed by the device. A thick device absorbs more light.

1.3 APPLICATIONS AND RECENT ADVANCEMENTS

The applications for plasmonic solar cells are endless. The need for cheaper and more efficient solar cells is huge. In order for solar cells to be considered cost effective, they need to provide energy at a smaller price than that of traditional power sources such as coal and gasoline. The movement toward a greener world has helped to spark research in the area of plasmonic solar cells. Currently, solar cells cannot exceed efficiencies of about 30% (First Generation). With new technologies (Third Generation), efficiencies of up to 40-60% can be expected. With a reduction of materials through the use of thin film technology (Second Generation), prices can be driven lower. In such perspective, plasmonic solar cells carry enormous scope and extensive applications in driving high efficiency at low cost. Some of the applications are:

1. **Space:** Certain applications for plasmonic solar cells would be for space exploration vehicles. A main contribution for this would be the reduced weight of the solar cells. An external fuel source would also not be needed if enough power could be generated from the solar cells. This would drastically help to reduce the weight as well.
2. **Rural Electrification:** Solar cells have a great potential to help rural electrification. An estimated two million villages near the equator have limited access to electricity and fossil fuels and that approximately 80% of people in the world do not have access to electricity. When the cost of extending power grids, running rural electricity and using diesel generators is compared with the cost of solar cells, many times the solar cells win. If the efficiency and cost of the current solar cell technology is decreased even further then many rural communities and villages around the world could obtain electricity when current methods are out of the question. Specific applications for rural communities would be water pumping systems, residential electric supply and street lights. A particularly interesting application would be for health systems in countries where motorized vehicles are not overly abundant. Solar cells could be used to provide the power to refrigerate medications in coolers during transport.

   Solar cells could also provide power to lighthouses, buoys, or even battleships out in the ocean. Industrial companies could use them to power telecommunications systems or monitoring and control systems along pipelines or other system.
3. **High Power:** If the solar cells could be produced on a large scale and be cost effective then entire power stations could be built in order to provide power to the electrical grids. With a reduction in size, they could be implemented on both commercial and residential buildings with a much smaller footprint. They might not even seem like an eyesore.

   Other areas are in hybrid systems. The solar cells could help to power high consumption devices such as automobiles in order to reduce the amount of fossil fuels used and to help improve the environmental conditions of the earth.
4. **Low Power:** One application which has not been mentioned is consumer electronics. Essentially, solar cells could be used to replace batteries for low power electronics. This would save everyone a lot of money and it would also help to reduce the amount of waste going into landfills.

Recent Advancements

- **Light Trapping**

As discussed earlier, being able to concentrate and scatter light across the surface of the plasmonic solar cell will help to increase efficiencies. Researchers have discovered a photonic waveguide which collects light at a certain wavelength and traps it within the structure. This new structure can contain 95% of the light that enters it compared to 30% for other traditional waveguides. It can also direct the light within one wavelength which is ten times greater than traditional waveguides. The wavelength this device captures can be selected by changing the structure of the lattice which comprises the structure. If this structure is used to trap light and keep it in the structure until the solar cell can absorb it, the efficiency of the solar cell could be increased dramatically.

- **Absorption**

Another recent advancement in plasmonic solar cells is using other methods to aid in the absorption of light. One way being researched is the use of metal wires on top of the substrate to scatter the light. This would help by utilizing a larger area of the surface of the solar cell for light scattering and absorption. The danger in using lines instead of dots would be creating a reflective layer which would reject light from the system. This is very undesirable for solar cells. This would be very similar to the thin metal film approach, but it also utilizes the scattering effect of the nanoparticles

1.4 OBJECTIVE

The objective of the present work can be summarized as follows:

1) To synthesize ZnS nanoparticles and study its morphology and structure by different characterization techniques available.
2) To gain knowledge about basic principles of plasmonic and organic solar cells, working, design and structure, their feasibility and operations.
3) To measure the following solar cell characteristics: short circuit current (I_{SC}), open circuit voltage (V_{OC}), fill factor and the dark and light I-V characteristics.
4) To study the effect of ZnS nanoparticles on all above values and calculate the efficiency of the fabricated Solar cell.