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PRODUCTION OF FLEXIBLE SOLAR CELLS

BY

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Παράβαση της ανωτέρω ακαδημαϊκής μου ευθύνης αποτελεί ουσιώδη λόγο για την ανάκληση του πτυχίου μου».

Ο Δηλών

Καραλής Κωνσταντίνος

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ABSTRACT

This thesis will examine the performance and efficiency of various materials in order to come up with new proposals for the better operation of flexible photovoltaics. Solar cells, highlights the principles behind the main technologies, and discusses future challenges in this area.

Flexible thin-film solar cells open the door to affordable power. In order to create lightweight, affordable solar modules that can be integrated into, rather than mounted on, a variety of surfaces, organic, inorganic, and organic-inorganic solar cells are deposited on flexible substrates using high-efficiency technologies. In addition to businesses and families seeking to use energy in the developed world and dealing with the growing cost of electricity produced using fossil fuels, these new photovoltaic technologies are poised to offer affordable, clean electricity to the 2 billion people who do not have access to the grid. Recent developments in flexible solar technology are the main topic of this review.

The aim of this study is to provide experts in the field with the appropriate information and results in order to exploit them in their own way in order to open the way for the green transition through flexible photovoltaic panels and the results that will emerge from this thesis.

ΠΕΡΙΛΗΨΗ

Στην παρούσα πτυχιακή θα εξεταστούν οι επιδόσεις και η αποδοτικότητα διαφόρων υλικών προκειμένου να προκύψουν νέες προτάσεις για την καλύτερη λειτουργία των εύκαμπτων φωτοβολταϊκών. Ηλιακές κυψέλες, υπογραμμίζει τις αρχές πίσω από τις κύριες τεχνολογίες και συζητά τις μελλοντικές προκλήσεις στον τομέα αυτό.

Οι εύκαμπτες φωτοβολταϊκές κυψέλες λεπτής μεμβράνης ανοίγουν το δρόμο για ηλεκτρική ενέργεια χαμηλού κόστους. Τα οργανικά, ανόργανα και οργανικά-ανόργανα ηλιακά κύτταρα εναποτίθενται σε εύκαμπτα υποστρώματα με τεχνολογίες υψηλής απόδοσης για την παροχή ελαφρών, οικονομικά αποδοτικών ηλιακών μονάδων που μπορούν να ενσωματωθούν σε διάφορες επιφάνειες, αντί να εγκατασταθούν σε αυτές. Αυτές οι νέες φωτοβολταϊκές τεχνολογίες είναι έτοιμες να παράσχουν φθηνή, καθαρή ηλεκτρική ενέργεια στα 2 δισεκατομμύρια ανθρώπους που δεν έχουν πρόσβαση στο δίκτυο, καθώς και σε επιχειρήσεις και οικογένειες που επιθυμούν να καταναλώσουν ενέργεια στον ανεπτυγμένο κόσμο και αντιμετωπίζουν το αυξανόμενο κόστος της ηλεκτρικής ενέργειας που παράγεται με τη χρήση ορυκτών καυσίμων. Η παρούσα ανασκόπηση επικεντρώνεται στα πρόσφατα επιτεύγματα στον τομέα της ευέλικτης ηλιακής ενέργειας.

Στόχος της παρούσας μελέτης είναι να παράσχει στους ειδικούς του χώρου τις κατάλληλες πληροφορίες και τα αποτελέσματα, ώστε να τα αξιοποιήσουν με τον δικό τους τρόπο, ώστε να ανοίξει ο δρόμος για την πράσινη μετάβαση μέσω των εύκαμπτων φωτοβολταϊκών πλαισίων και των αποτελεσμάτων που θα προκύψουν από την παρούσα διατριβή.

ACKNOWLEDGEMENTS

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I am also sincerely thankful to my colleagues, whose valuable input and thoughtful comments contributed to shaping the final version of my thesis.

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CHAPTER 1: POWER GENERATION AND RENEWABLE ENERGY SOURCES

1.1 Introduction in Power Generation and Conventional Energy

In the modern word we energy is a significant and crucial issue. Word is so hinge on energy that we can’t think our existence without that. Types of energy are so many that it takes so long to talk about each one. Maybe electricity is the most favourable and prudent type of energy. In every aspect of our life we use energy. In order to operate industry, we need electricity. To light up our houses and streets at night we need electricity. To run the computer, mobile phones, smartphones we need electricity. To watch TV, listen to radio and other devices and machines we need electricity. So the use of electricity knows no limitations. Modern word is clearly out of the question without electricity. So it is most important and most needed source of energy. (Khan, K. A. and Hasan, M, 2018)

The ability of a physical system to carry out work is known as energy. Energy can take many different forms, including heat, electrical, kinetic or mechanical, light, and potential energy. The law of conservation of energy states that even though energy can change forms, a system's overall energy stays constant. For instance, when two pool balls collide, they may come to rest, releasing energy that at the moment of impact becomes sound and possibly heat. The newton-meter (N-m) or joule (J) is the SI unit of energy. The joule is also the SI unit of work. Most of the energy used by humans comes from the sun, either directly or indirectly. The energy supplies that have been in use for a long period are considered non-renewable. The supply of fuel is scarce. All this petroleum products are carbon with a lot of energy that has been broken down anaerobically by the sun's light. When fossil fuels or petroleum products are absorbed, a lot of toxins are released into the environment. (Khan, K. A. and Hasan, M, 2018)

1.2 Conclusions and impact of Conventional Sources in today’s world

Byproducts of burning fossil fuels are the biggest threat to human health and future generations worldwide. They also play a major role in the global economy and environmental injustice. A significant portion of harmful air pollutants and carbon dioxide (CO2), the primary greenhouse gas produced by humans, are included in the emissions. The harm to the entire world may be amplified by the interactions between air pollution and climate change. The effects include diseases, respiratory conditions, and impairment of cognitive and behavioral development. These conditions can all be sown in a womb and have an immediate negative impact on a person's health and ability to function throughout their life. Pollution and climate change make people less resilient and the communities they live in less equitable and fair because they impair people's health, capacity for learning, and ability to contribute to daily tasks in society. Due to their immature defense mechanisms and rapid development, developing embryos, young children, and middle-aged individuals are disproportionately affected by these exposures. This effect is compounded in low-income and third-world countries where poverty and resource scarcity exacerbate the effects. No nation will be able to escape this enormous issue unless we take decisive action, but even high-income nations are feeling the effects of pollution from fossil fuels, climate change, and the ensuing increase in inequality and environmental injustice, particularly in low-income and communities of color. The state of pediatric health worldwide is critical, and if decisive action is not taken, the results could be disastrous. Thankfully, there are tools and strategies available to stop and lessen pollution and climate change, with significant financial gains possible. The health and wellbeing of today's and tomorrow's children is a shared concern of all governments and communities. This common value offers a potent political lever for action. Each and every governor's goal must be An unrelenting effort to consistently implement policies to lessen this issue, examine the data on the negative effects of fossil fuel pollution on health, emphasizing the effects on neurodevelopment, and provide a brief overview of the strategies that can be used to create a low-carbon economyas well as some instances of successful interventions that have improved both health and the economy. (Int. J. Environ. Res. Public Health 2018)

Fossil fuels emit harmful air pollutants into the atmosphere even before they burn. According to a 2017 study that was published in Environmental Health Perspectives, 17.6 million Americans are exposed to dangerous air pollutants daily from gas and oil, as well as from transportation and processing facilities. These include benzene, which has been linked to childhood leukemia and blood issues, and formaldehyde, a chemical that causes cancer. A thriving industry will continue to spread that pollution into more backyards despite mounting evidence of the practice's harmful health effects. Hazardous airborne particulate matter is still released by mining operations, which is especially detrimental to the workers. Massive amounts of carbon toxins that are naturally stored in the wild can be released by strip mining, especially in areas like Canada's boreal forest. (Melissa Denchak, 2022)

Carbon dioxide is not the only gas released during the breakdown of fossil fuels. Most of the soot in our air, the sulfur dioxide emissions linked to acid rain, and 35 percent of the dangerous mercury emissions in the United States are from coal-fired power plants. Meanwhile, cars, trucks, and boats that run on fossil fuels are the primary sources of dangerous carbon monoxide and nitrogen oxide, which contribute to smog on hot days and create the conditions for respiratory illnesses from extended exposure.

(Melissa Denchak, 2022)

1.3 Renewable Energy

More sustainable energy technologies must be used to replace conventional electricity generation resources like fossil fuels due to the current global demand, especially in developed and developing countries. Because fossil fuels contribute to global warming and climate change, their use as an energy source is gravely damaging the environment. The amount of greenhouse gases released into the atmosphere as a result of electricity production has significantly increased in recent years. Renewable energy technologies, such as solar, hydro, wind, geothermal, biomass, and hydrogen energies, have been developed to produce electricity in order to address the current environmental crisis. As people become more conscious of the need to maintain a clean environment, renewable energy sources—which can produce electricity with nearly zero emissions of air pollutants—are gaining more and more attention on a global scale. In addition to supporting sustainability, renewable energy has advantageous economic effects. It helps the economy by lowering the price of electricity bills because it generates energy from renewable, natural resources.

Customers can sell the electricity they generate back to the power grid companies, so it can also be a secondary source of income. While the use of renewable energy sources to generate electricity is growing, most power is still produced using fossil fuels because renewable energy is more erratic and requires a larger initial investment. For example, photovoltaic systems can only function during the day, wind turbines can only function when there is enough airflow, and hydro turbines can only function when water flow produces potential energy. Globally, scholars are conducting rigorous analysis aimed at enhancing the effectiveness of renewable energy technology while also surmounting its shortcomings and constraints. (Ang, T. Z., Salem, M, 2022)

Due to a lack of infrastructure, funding, and other resources, the majority of nations still rely on fossil fuels to power their economies in this century. This is because renewable energy sources cannot be fully utilized to produce electricity. However, the generation of electricity in the electric power sector is growing at an astronomical rate these days due to children's awareness of environmental issues. The data and analysis of fossil fuel consumption, along with a trend of the various types of RE usage for electricity generation, are shown in the picture below, comparing the generation of fossil fuels to renewable energy sources. (Ang, T. Z., Salem, M, 2022)

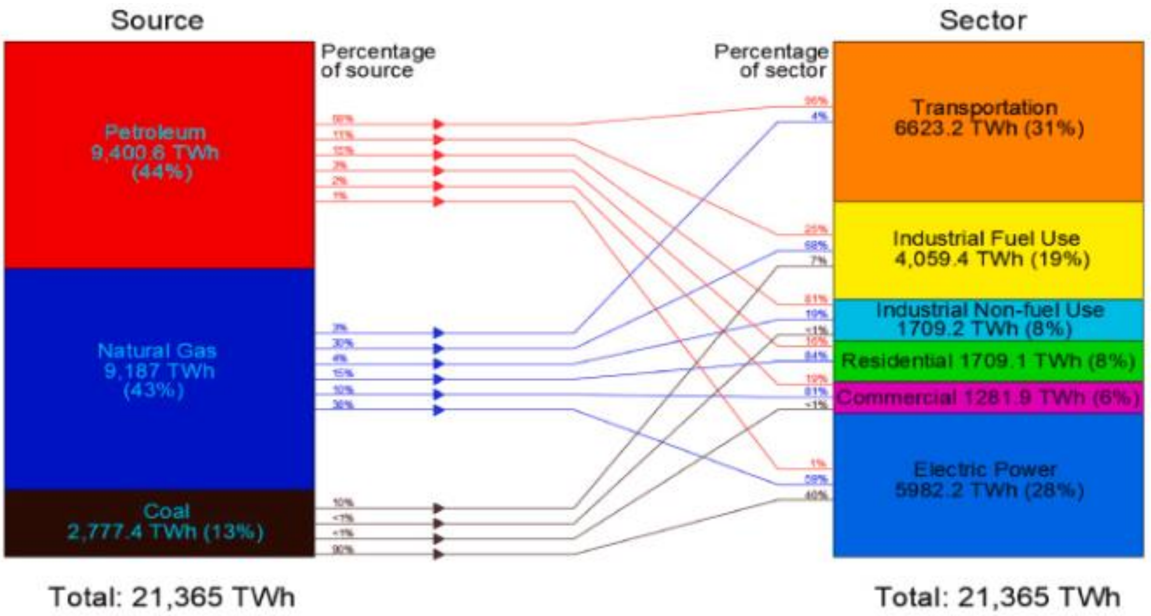

Fig. 1: depicts the US's distributed sectors and overall use of fossil fuels in 2020. The United States used 21,365 TWh of fossil fuel in total in 2020. With a total contribution of 9400.6 TWh, petroleum made the largest contribution (44%). The contribution of natural gas was 9187 TWh, or 43%. With 2777 TWh utilized for power generation, coal had the lowest usage. Five sectors are powered by fossil fuel resources, as the figure illustrates. In 2020, the transportation sector accounted for 31% of all fossil fuel usage, or 6623.2 TWh. In addition, while natural gas produced 3529.5 TWh of electricity in the same year, coal contributed 2392 TWh, or 90% of the total electricity produced.

(Adopted from Ang, T. Z., Salem, M Study, 2022)

1.3.1 The importance of Green Transition

It is imperative that we make the green transition to a sustainable economy. A sustainable economy drives into a low-carbon society that promote biodiversity and the sustainable use of natural resources. The renewable energy transition is a significant part of the green transition. Eliminating fossil fuels and replacing them with clean energy methods is the key objective in order to make this transition easier. (Finish Ministry of the environment, 2023)

The green transition is a critical step because our economic development is based on the overconsumption of natural resources and is thus built on an unsustainable foundation. Biodiversity loss and climate change cause tremendous issues and consequences to the economy and generally speaking to society. With the green transition, we can decrease emissions a little bit faster and diminish climate change, as well as preserve and make better the state of the environment. The green transition will speed up the economy of the countries. It will improve our healty-competitiveness and build wellbeing within the planetary boundaries. The green transition can be end up into a new driving force of our economy as there is a growing demand for low-carbon solutions that strengthen the natural environment around the world. How well we will succeed in alleviate climate change and adapting to it and decrease biodiversity loss will have a big step on the long-term sustainability of the public finances, well-being of the upcoming generations and state of the environment. The green transition will also nourish comprehensive security. Replace gradually fossil fuels of foreign origin and increasing local production of clean energy will improve our reliability of supply. (Finish Ministry of the environment, 2023)

1.4 Forms of Renewable Energy

1.4.1 Solar Energy

The sun is one of the primary sources of free energy on our planet. Captured solar energy is being used to generate electricity using modern technologies. Since these methods have already been shown to be effective, they are frequently employed globally as renewable alternatives to conventional non-hydro technologies. In general, solar energy has the potential to adequately meet the world's energy needs if the technologies required for its harvesting and supply were widely accessible. Solar research is closely related to the ongoing effort to reduce global carbon emissions, which has been a major environmental, social, and economic concern in recent decades. For example, 696,544 metric tons of CO2 emissions have been cut or eliminated in the USA as a result of the installation of 113,533 residential solar systems. Adoption of solar technologies would therefore significantly lessen and mitigate issues with energy security, climate change, unemployment, and equity. It is also a fact that because it runs on no fuel at all, like gasoline or petroleum, its use will be significant in the transportation industry. (Kabir, E., Kumar, P, 2018)

1.4.2 Wind Energy

Wind power is one type of renewable energy that harnesses the force of the wind to generate electricity. It involves using wind turbines to generate electricity by using the spinning motion of blades driven by airflow. This requires specific technologies, such as a generator at the top of a tower, behind the blades of a wind turbine, or in the head of the turbine. When wind blows overhead, the blades on top of a wind turbine tower rotate.

Air movement causes the blades of a wind turbine to rotate. That motion spins a generator situated directly downwind of the nacelle's blades, which house all the other parts of a turbine. The generator generates energy. We can keep producing energy as long as wind is available because it is renewable. Modernizing the turbines increases their efficiency, allowing them to provide clean, reliable energy to the grid, homeowners, and communities even in places with less wind than these.

Wind energy is also a form of clean energy. This is because wind turbines don't release greenhouse gases into the atmosphere, such as carbon dioxide, which reduces pollution in the air and oceans that may harm human health or the environment. Many places, including isolated or distant places like islands far from the mainland where access to the utility grid is limited, can benefit from wind energy. It is also possible to build offshore and on land wind farms. Installing wind energy has numerous financial and economic benefits as well.. Wind turbines are inexpensive to operate, and they can reduce utility costs for low-income families and communities. They can also generate income through the sale of excess energy generated by a turbine located on their property, benefit from tax breaks and other financial incentives, and create jobs.

(Adopted from Wind Energy Technologies Office **)**

1.4.3 Geothermal Energy

The heat that exists within the Earth is the source of geothermal energy. Drilling and resource evaluation are two of the techniques used to extract natural steam and hot water for industrial processes, space heating, and electricity production. Heat and fluid are continuously circulated in geothermal fields; the fluid enters the reservoir through recharge zones and exits through discharge areas like wells and hot springs. Waste fluids are reinjected into the reservoir through wells during industrial use to make up for the fluids that are extracted and prolong the field's useful life. Although geothermal energy is partly renewable, hot fluid production rates are frequently higher than recharge rates.

(Barbier, E.2002)

1.4.4 Hydropower Energy

The world's largest renewable energy source at present is hydropower, which plays a vital role in generating electricity globally. Up until the 2030s, hydropower is expected to continue as the primary renewable energy source, generating more electricity than the combined output of all other renewable technologies. It will therefore continue to be essential for improving system flexibility and decarbonizing the power system. Hydropower is predicted to eventually be surpassed by wind and solar energy, but for the time being it will remain a major dispatchable power source to support variable renewables.

Additionally, pumped storage may play a major role in counteracting variations in solar and wind power generation. It is predicted that the global hydropower expansion will slow down in the current decade in the absence of major policy changes. The slower rate of project development in Europe, Latin America, and China is the reason for this downturn. Nonetheless, these decreases are being somewhat offset by growth in the Middle East, Africa, and Asia Pacific. In addition, hydro production is being disrupted globally by increasingly unpredictable rainfall patterns brought on by climate change.

(Adopted from Hydropower IEA)

1.4.5 Bioenergy

Biological material from living or recently deceased organisms is known as biomass, and it is primarily used to describe plants or materials derived from plants. Biomass is a renewable energy source. Renewable energy produced from materials obtained from biological sources is known as bioenergy. Either directly or indirectly—once it is transformed into another kind of energy product like biofuel—biomass can be used. An exhaustive spatial and statistical count of all the different types of biomass is called an estimate of biomass resources. Estimating the potential energy content of biomass resources is known as bioenergy potential estimation.

The use of bioenergy could help stabilize atmospheric concentrations of greenhouse gases below dangerous levels, help achieve the goals of the framework convention on climate change, and help fill the gap left by fossil fuels. This raises the question of how much and how far bioenergy could help. A thorough grasp of the kinds, sources, quantities, and distribution of bioenergy potentials may be possible with research on bioenergy potential estimation. How much bioenergy can help reduce greenhouse gas emissions, how much it can replace and supplement energy shortages, and how best to structure the development and use of bioenergy can all be determined using these factors.

The first step in comprehending bioenergy from the industrial chain and its future development potential is to estimate its bioenergy potential. Scholars have conducted extensive research on biomass and bioenergy potential at the national, local, and regional levels in order to gain a comprehensive understanding of the bioenergy sector. Future scenarios involving biomass and bioenergy potential could predict the prospects for the development of bioenergy and its relative impact on environmental protection. Divergent opinions exist regarding the potential for bioenergy supply in the future. The debate has not yet reached a consensus due to the complexity of the influencing factors affecting bioenergy potential. As is well known, the variables affecting bioenergy potential interact with one another and are difficult to distinguish apart. Future studies on the potential of bioenergy are carried out using simplified estimation models at both the global and regional levels. Even though we have made great progress, there are still certain shortcomings and undeveloped areas that need to be addressed. (Long, H., Li, X, 2013)

1.4.6 Nuclear Energy

Nuclear energy is the energy emitted from the protons and neutrons that make up an atom's nucleus. This energy source can be produced in two ways: fission, which happens when atoms split into multiple pieces, or fusion, which happens when nuclei fuse together. Nuclear fission is the process by which the nucleus of an atom splits into two or more smaller nuclei while releasing energy. For instance, when a uranium is hit by a neutron, its nucleus splits into two or three neutrons and two smaller nuclei, such as a barium and a krypton nucleus. These additional neutrons will hit nearby uranium-, which will split and multiply to produce more neutrons, starting a chain reaction in a matter of seconds. Every time the reaction occurs, energy is released as radiation and heat. Similar to fossil fuels like coal, gas, and oil, heat can be converted into electricity in a nuclear power plant.

Nuclear reactors and related equipment contain and regulate chain reactions that produce heat through fission in nuclear power plants. These reactions are typically powered by uranium. Steam is produced when the heat warms the reactor's cooling agent, usually water. After that, the steam is directed toward revolving turbines, which turn on an electric generator to produce low-carbon electricity. (Andrea Galindo, 2022)

1.4.7 Tidal Energy

The sun and moon's gravitational pull creates tidal currents, which are especially concentrated in small waterways like those surrounding islands and inlets. Tidal energy is predicted to be a global resource with 800-1200 TWh, which means it will play a major role in decarbonizing our energy systems. Tidal energy production can be forecast hundreds of years ahead of time. The well-known cycles of the moon, sun, and earth are the only factors that affect tidal currents; weather has no bearing on them.

Tidal energy's long-term predictability makes it one of the most reliable renewable energy sources on the market. It is crucial for preserving grid balance and guaranteeing a baseload of electricity in Europe, where all energy is derived from renewable sources.

Although tidal range technology also uses tides to generate electricity, it is not the same as tidal stream devices. Instead of using the flow of tidal currents, tidal range installations use the difference in sea levels between high and low tides to generate energy. Similar to hydropower, tidal range relies on a barrier or dam to hold back a significant amount of water. Water discharges from one side to the other due to the difference in water height between the inside and outside of the impounded area. Power is generated by forcing this water through internal turbines in the structure. (Adopted from Ocean Energy Europe)

1.5 Introduction in Photovoltaics

1.5.1 History of Photovoltaic Technology

Becquerel is generally credited with discovering the photovoltaic effect. Exposure of platinum electrodes coated in silver chloride or bromide to light in an aqueous solution caused him to observe a photocurrent (strictly speaking, this is a photoelectrochemical effect). In 1873 and 1876, respectively, Smith and Adams published the first reports on photoconductivity while working with selenium. Pochettino discovered photoconductivity in an organic compound called anthracene in 1906, and Volmer did the same in 1913. In the late 1950s and early 1960s, it became possible to use organic materials as photoreceptors in imaging systems. Research on photoconductivity and related topics has increased as a result of both the scientific and commercial potential. It was found that many common dyes, including methylene blue, had semi-conductive qualities at the beginning of the 1960s. These dyes were among the first organic substances to show the PV effect later on. Additionally, the PV effect has been shown in a wide range of significant biological molecules, including structurally related phthalocyanines (PC) and carotenes, chlorophylls, and other porphyrins. Unlike inorganic solar cells, organic photovoltaics have not yet made it to the market, despite numerous advancements over the years. In 1954, Bell Laboratories developed the first inorganic solar cell. Its efficiency was 6% and it was based on Si. In the laboratory, the efficiency of crystalline Si solar cells has increased over time to 24%. Si-based solar cells, which make up 99% of all PVs, are currently the most widely used type of PVs. As production costs have decreased and efficiency has increased, the global photovoltaic market has grown. The demand for solar energy has increased steadily over the last 20 years, averaging growth rates of 20–25% annually, and reaching 427 MW in 2002. The price of Si PVs has dropped significantly over the past 50 years thanks to research and innovation, reaching a point where current technology allows. Nevertheless, this technology is limited to specific markets despite significant efforts to further lower the cost of Si-based PVs. As a result, semiconductor photovoltaics still produce less than 0.1% of the energy produced worldwide. (Spanggaard, H., & Krebs, F. C. 2004)

1.5.2 Photovoltaics in the modern world

Because of its rapid learning curves and steady growth, solar photovoltaics is now a very cost-competitive technology that is ready to drastically reduce CO2 emissions. However, many scenarios that assess global decarbonization pathways—based on integrated assessment models or partial-equilibrium models—do not acknowledge the critical role that this technology could play. One such scenario is that future PV capacity may be significantly lower than what the PV community has projected. (Victoria, M., Haegel, N, 2021)

Whether or not we are able to stay on a course that is consistent with the Paris Agreement and keep the increase in global temperature to 1.5°C over preindustrial levels will depend on our capacity to cut greenhouse gas emissions by 2030. Today's mature technology, solar photovoltaics, is prepared for multi-terawatt deployment and can help reduce emissions in the near future. Solar photovoltaics generated 2.8% of the world's electricity at the end of 2019, an order of magnitude less than conventional technologies, but with a very steep growth curve. Numerous factors contribute to this technology's rapidly increasing cost and rapid adoption. The modular, or granular, nature of PV is one particularly intriguing feature. In rooftop installations, identical solar panels with a combined power of hundreds of watts are used in utility-scale power plants, the number of panels can reach millions. In contrast to other technologies, the small unit size and low unit investment have allowed for a much faster scaling through replication. In addition, multiple markets were served in parallel due to the high modularity and universal access to solar resources. Solar energy is currently the most affordable source of electricity in many parts of the world, and it is predicted that a cumulative capacity of more than 1 TW will be achieved before 2023. Despite technological advancements, the critical role has not been identified in many studies involving future energy scenarios. (Victoria, M., Haegel, N, 2021)

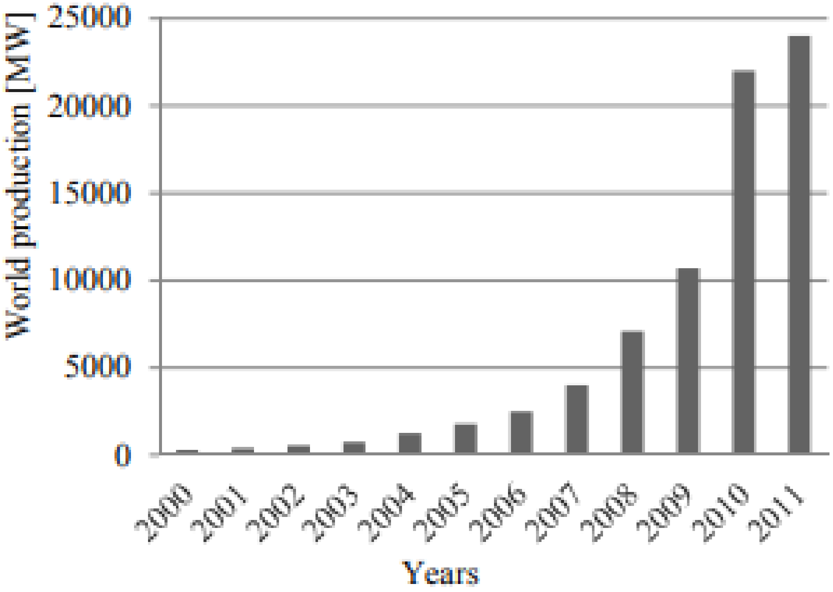

Fig. World production of solar cells/photovoltaic modules in megawatts (Adopted from Dobrzański, L.A., Drygała, A.2012. Monocrystalline silicon solar cells applied in photovoltaic system. (Journal of achievements in materials and manufacturing engineering,)

1.5.3 Mechanism of PV Cells

Electricity is the most crucial resource for the development of human civilization since it can be used to measure a society's standard of living. There are several resources available to generate electricity, ranging from nuclear reactor systems to different methods like burning fossil fuels. Sunlight is the most plentiful, safest, and clean energy source that can be used to sustainably drive economic growth among various energy sources. Directly harvesting electrical or photovoltaic energy from sunlight is accomplished through the photovoltaic effect., as discovered in 1839 by French physicist Alexandre-Edmond Becquerel. Semiconductor materials exhibit this effect; they are distinguished between conductors and insulators by their electrical conductivity in the middle. Photons that reach semiconductor materials through incident radiation are captured by their electrons, which results in the electron moving into a state of greater energy. These electrons can break their nucleus and start to circulate within the material if their energy state exceeds the band gap, or threshold value, of the material. The circuit starts to conduct electricity as a result of the potential difference between the terminals.

(Singh, B. P., Goyal, S. K., 2021)

The most efficient way to use solar energy as a growing energy source is to use solar cells to transform solar radiation into photoelectric energy. On the other hand, the maximum amount of light that can be converted into electricity is referred to as "power conversion efficiency" (PCE). With the Shockley-Queisser model and formalism, the PCE—or ratio of incident photon energy to electrical output for a uni-junction solar cell is computed. For every absorbed photon with perfect charge-selective contacts, the SQ formalism assumes that all photons with energies above the bandgap yield free electrons and holes, giving one electron to the electric current. Furthermore, an evaluation of their basic limits and present performance is required to ascertain how a particular kind of solar cell and technology deviates from its SQ limit in real-world applications. After that, the adjustments required to bring the SQ limit closer to reality can be made. Solar radiation energy is directly converted into electrical energy by photovoltaic cells (PV) using the photovoltaic effect. The combination of two semiconductor regions—which can be either n-type (materials with an excess of electrons, known as negative charges) or p-type (materials with an excess of holes, known as positive charges)—represents the architecture of PV cells. Despite being electronically neutral in both situations, this kind of material is mostly reliant on the electron concentration. (Singh, B. P., Goyal, S. K., 2021)

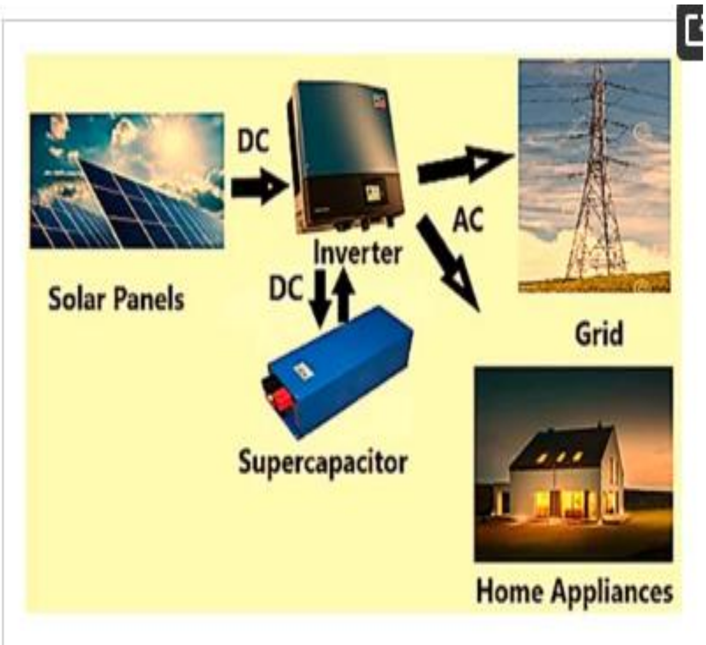

Figure. The basic components of a PV system. (Adopted from Al-Ezzi, A. S., & Ansari, N. M. (2022). Photovoltaic solar cells: a review.)

1.5.4 Types of PV Cells

1.5.4.1 Monocrystalline Silicon Cell

Monocrystalline silicon is therefore the more expensive alternative, which has the highest efficiency at about 15% of the solar PV cells. They take up less area than other cells simply because they generate more energy and can deliver up to four times the power of thin film solar panels. They also have a longer lifespan than other panels and work better in less luminous conditions.

The only aspect rather complicating industrial solar panel use is the cost which often implies not being the preferred attitude among private house owners. Dirt or shade also can effect the employment and sometimes deconstruction processes as in cell production a lot of waste is generated since wafers cut must be demolished. (Janet Richardson, 2024)

1.5.4.2 Polycrystalline Silicon Cells

Polycrystalline solar panels, with an efficiency of 13%, are often considered a more cost-effective option, especially for homeowners. These panels are composed of multiple smaller silicon crystals that are fused together and then reformed. The manufacturing process for these panels is simpler and produces less waste compared to monocrystalline panels. Although they are more susceptible to heat, which can shorten their lifespan, they generally perform comparably to their pricier counterpart. The primary drawback of polycrystalline solar panels is that a greater quantity is required due to their lower energy conversion efficiency. (Janet Richardson, 2024)

1.5.4.3 Thin Film Cells

Thin film solar panels, with an efficiency of 7%, are one of the least efficient options available, but they are also the most affordable. They perform well in low light conditions, including moonlight, and are constructed from non-crystalline silicone that can be applied as a thin film onto other materials like glass. The primary benefit is their ability to be mass produced at a lower cost, although they are more suitable for environments where space is not a significant concern. One major drawback of thin film solar panels is their limited use in residential settings and their faster degradation compared to crystalline cells. (Janet Richardson, 2024)

1.5.4.4 Hybrid Solar Panels

The highest efficiency is achieved by hybrid solar panels, which combine monocrystalline and amorphous cells. Their efficiency is 18%. There are several varieties of hybrid cells available, but they are currently more expensive because they are still in the research and development stage. (Janet Richardson, 2024)

CHAPTER 2: FLEXIBLE SOLAR CELLS

2.1 An Overview into the Flexible Solar Cells

A ground-breaking advancement in solar photovoltaic technology, flexible solar cells provide a flexible and adaptive method of capturing solar energy. Flexible solar cells can adapt to curved or uneven surfaces because they are made on flexible substrates like plastic or thin metal foils, in contrast to traditional rigid solar panels. Numerous uses are made possible by this flexibility, such as incorporation into wearable technology, rollable solar blankets, and other unusual surfaces. Organic photovoltaics (OPV), thin-film technologies like amorphous silicon, and newly developed materials like perovskites are the most frequently utilized materials in flexible solar cells. These substances offer the solar cells the flexibility they require to bend and conform without sacrificing their efficiency of energy conversion.

The lightweight and portable nature of flexible solar cells is one of their main advantages; this makes them perfect for situations where traditional, rigid solar panels would not be feasible. Additionally, the adaptability makes it possible for smooth integration into a variety of surfaces, increasing the opportunities for solar energy harvesting in unusual settings. Additionally, portable and off-grid power solutions are a great fit for flexible solar cells. They are portable and compact because they are simple to roll up or fold. For uses like camping, outdoor recreation, and emergency power supplies, this makes them useful.

(Journal of Polymer Science and Engineering 2024,)

Even with the encouraging benefits, there are still difficulties in reaching maximum efficiency and sustaining durability over time, particularly in outdoor environments. Researchers are actively pursuing improvements in manufacturing techniques and material science to increase the stability and efficiency of flexible solar cells. It has been said that in modern culture, the electron is the ultimate form of money. The most widely used energy source is electricity because it can be converted into labor quickly, is portable, quiet, and clean.

(Journal of Polymer Science and Engineering 2024,)

2.2 Prons and Cons of Flexible Solar Cells

The main advantage of flexible solar cells is their degree of flexibility. They can be installed in places where traditional solar panels cannot because of their small weight. For instance, if structural issues prevent your home from passing the roof test needed for the installation of solar shingles or panels, you can always select ultra-thin flexible solar cells. Another advantage of flexible solar panels is their ease of attachment to a variety of objects, including laptops, cell phones, and cameras, to name a few. The Fisker Karma solar roof is a fantastic illustration of this, as the flexible solar panel is expertly integrated to match the curved roof of the vehicle. Installing flexible solar panels is significantly less expensive than installing regular solar panels because they are lightweight and require less work to install. There are some limitations with flexible solar panels, though. They are not appropriate for large-scale solar projects that require more durable and dependable solar panels. The efficiency range of 11–13% for these flexible solar panels is much lower than the 14–17% efficiency range for monocrystalline or polycrystalline panels. All we can do is hope that more advancements in technology will enable the production of more flexible and efficient solar panels.

(Adopted from Oorjan Blog, 2018)

2.3 Third Generation Solar Cells

2.3.1 Third Generation Solar Cells – Overview

Third generation PV technologies are solution-processed, semiconducting-based technologies. Third-generation solar cells, according to Green, are those that can maintain a low cost of production while achieving high power-conversion efficiency. When combined with thin-film technologies, their application could have a significant economic impact, positioning solar energy as one of the most affordable and widely available options for future energy production. Because of their adjustable bandgap, thin-film technologies are a superior choice for light harvesting. This invention is thought to have the potential to revolutionize photovoltaic technologies by improving device performance while lowering fabrication costs and lengthening device lifetimes.Third-generation solar cells are therefore being extensively

studied and developing quickly. Examples of these include dye-sensitized solar cells (DSSCs), perovskite solar cells (PSC), and quantum dot-sensitized solar cells (QDSSCs). Third-generation solar cells (SCs) also include hot-carrier, multiple exciton cells, up- and down-conversion, and organic photovoltaics (OPVs).
(Shah, N., Shah, A. A., 2023)

2.3.1.1 Perovskites

Perovskite solar cells (PSCs) have become a promising thin-film photovoltaic (PV) technology due to the high light-absorption coefficient, long carrier diffusion length, and solution processibility of metal halide perovskite materials. At 25.5%, PSCs currently hold the highest power conversion efficiency (PCE) of any solar cell. This exceeds the record set by copper indium gallium selenium (CIGS) solar cells and is comparable to the efficiency of crystalline silicon solar cells. Moreover, scale-up deposition methods for charge transport layers and perovskites, including screen printing, doctor-blade coating, slot-die coating, and spray deposition, facilitate the development of large-area perovskite solar modules. There is a lot of potential for practical use, as evidenced by the recent report of a certified efficiency of about 18% for a PSC sub-module larger than 800 cm. However, perovskite-based tandem solar cells with a theoretical PCE higher than that of single-junction PSCs also achieve notable advancements due to the decrease in defect density and increase in carrier diffusion length in both narrow-bandgap and wide-bandgap perovskite absorbers. The maximum certified efficiency of the perovskite-based tandems has now increased to more than 29%. (Wu, T., Qin, Z., 2021)

The development of a diffusion barrier against ion migration, additive engineering, the design of chemically inert carbon-based electrodes, and the creation of a cell encapsulation technique to lessen lead leakage from a broken PSC module are all responsible for the recent improvements in the long-term stability of PSCs against heat, light, and dampness in addition to their efficiency gains. The printable PSCs were demonstrated to satisfy the most widely recognized international standards for cutting-edge photovoltaic technology. (Wu, T., Qin, Z., 2021)

2.3.1.2 Advantages of Perovskites and what’s holding them back

In short, the goal of perovskite solar cells is to make solar energy more efficient and less expensive. High efficiencies, low potential material costs, and lower processing costs are all potential benefits of perovskite photovoltaics. The ability of perovskite photovoltaics (PVs) to react to different light wavelengths gives them a significant advantage over traditional solar technology. This allows them to generate electricity from a greater percentage of the sunlight that reaches them. Additionally, they are lightweight, flexible, semi-transparent, and have customized form factors. Naturally, researchers and designers of electronics are confident that these features will allow solar cells to be used in a wide range of additional applications.

Compared to other established solar technologies, perovskite solar cell technology is still in its infancy as a result of several unresolved issues, despite its enormous potential. One issue is their overall cost (for a number of reasons, chief among them being that gold is currently the most widely used electrode material in perovskite solar cells), and another is that less expensive perovskite solar cells don't last very long. Additionally, perovskite photovoltaics degrade quickly when exposed to moisture, and the byproducts of this degradation target metal electrodes. The weight and cost of the cell may increase if the perovskite is heavily encapsulated for protection. Another problem is scaling up; small cells have been reported to achieve high efficiency ratings, which is ideal for lab testing but too small to be used in an actual

One of the main problems is toxicity. One of the breakdown products of perovskite is a material known as PbI. This is known to be harmful, and there are worries that it might cause cancer, though this hasn't been confirmed yet. Additionally, lead, a major pollutant, is used in many perovskite cells. Scientists are always looking for alternatives, and they have already used tin to create functional cells.

(Adopted from https://www.perovskite-info.com/perovskite-solar)

2.3.1.3 Organic Photovoltaics

One promising option for using sustainable solar energy is organic photovoltaic (OPV) technology. Its power conversion efficiency (PCE) is rapidly increasing and has a lot of potential for real-world uses. The advancement of OPV cells over the past three decades has been largely attributed to the creation of new materials, the improvement of device processing techniques and blend morphology, and a deeper comprehension of device physics. One of the main benefits of OPV cells is their solution processability, which makes it possible to produce them in large quantities at a low cost using scalable printing technologies. Even though the PCEs of single-junction OPV cells have surpassed 16%, most of the devices with state-of-the-art performance were made using spin-coating techniques at tiny areas below 0.1 cm2, which is far from useful applications. Furthermore, the spin-coating method is unsuitable for large-scale production and wastes a lot of solution. Therefore, when designing highly efficient OPV materials, it is necessary to consider their applicability in scalable fabrication technologies over relatively large active areas. (Cui, Y., Yao, H, 2023)

Three main issues still prevent OPVs from being used in commercial settings: batch-to-batch variations in organic source materials make performance consistency challenging; OPV modules' power conversion efficiency is still lower than that of any commercially available competitors; and OPVs' operational lifetime is far shorter than that of inorganic products. Efficiency does not determine a PV technology's worth in and of itself, but because of all the soft costs and balance of systems involved in installing PV power, even a minimum efficiency is necessary, even if a panel costs almost nothing to manufacture. Due to their lightweight and mechanical flexibility, OPVs are expected to have balance of systems costs significantly lower than traditional racked PV systems. This is because their low overhead, labor, and material costs are significantly reduced. Everyone agrees that the performance of OPVs will keep getting better, but the true difficulty at this point is transferring the remarkable efficiency gains observed in laboratory-scale devices to the module scale. (Darling, S. B., & You, F. 2013).

2.3.2. Non-Flexible Design Philosophy – Third Generation Solar Cells

Because their design philosophy did not prioritize flexibility, the solar cells in this category are regarded as non-flexible. Although flexible solar cells can be used with Quantum Dot and Multi-Juction solar cells.

2.3.2.1 Multi Juction-Solar Cells

By employing multiple p-n semiconductor junctions connected in series to absorb various solar spectrum wavelength ranges, an MJSC can achieve light conversion efficiencies that are higher than the theoretical S-Q limit. (Nikoletatos and Halambalakis, 2018). When multiple semiconductor plates were stacked, the topmost cell had the highest energy bandgap and the bottom semiconductors had decreasing bandgaps. This concept of MJSCs was first presented in 1955 (Jackson, 1955). In order for the MJSC to function, sunlight must first pass through its top contacts. After that, light (photons) from the sun's shorter wavelengths are collected by the top cell, which has the highest bandgap energy. When a photon's bandgap is smaller than that of the top cell, it is transmitted through to the lower layers. Each semiconductor absorbs photons with energy between its energy bandgap and the plate above it since each plate is transparent to wavelengths longer than its absorption edge (Irvine, 2017). As each layer has a different voltage, the foundation of MJSC operation demonstrated in 1960 that the semiconductor materials should be connected by an ohmic contact in a series connection (Wolf, 1960). The breakthrough came in 1988 when various semiconductor layers were connected by a double heterostructure Gallium Arsenide (GaAs) tunneling junction with low resistance, achieving a 20% efficiency. (Sugiura et al., 1988). According to Cotal et al. (2009), the tunneling junction is made up of a tunneling diode that allows electrons from the lower cell's conduction band to recombine with the holes in the higher cell's valence band with the least amount of energy loss. The triple junction (3-J) solar cell, which has three semiconductor absorbers divided by a tunneling junction, is the most widely used MJSC. A 5-junction solar cell with an efficiency of 35.8% for space applications and 38.8% for terrestrial applications was created over the course of the following 30 years by stacking additional junctions (Chiu et al., 2014). According to Geisz et al. (2020), MJSCs stacked six junctions to achieve the highest light conversion efficiency of 39.2% when one sun is illuminated and 47.1% when 143 suns are concentrated. As a result, space exploration missions currently use MJSCs' high efficiencies as their energy source. Additionally, MJSCs are the way of the future for terrestrial concentrated photovoltaic systems (CPV) to meet the growing demand for energy while balancing carbon emissions (Bett et al., 2009).

For MJSCs, two main challenges are noted. On the one hand, the main obstacle keeping MJSC modules from overtaking established Si single junction solar cells in the market is their high price. Because of this, MJSCs can only be used in specific applications where surface area is a constraint, like space applications or unmanned aerial vehicles and drones. However, an increase in MJSC efficiency could reduce the high cost of long-term solutions that use renewable energy sources. Therefore, efficiency and cost must be balanced when choosing solar cells.

Commercialized MJSCs have an efficiency of around 30%, which is below the S-Q limit of single junction solar cells. A 3-J solar cell's optimal theoretical efficiency is about 50% at one sun concentration and roughly 64% at 1,000 suns. To increase the efficiencies of six junction solar cells, additional junctions can be deposited with an efficiency of roughly 75%. Efficiency is affected by temperature, spectrum, and concentration. Theoretical efficiencies, for example, are only 10–20% higher at the maximum concentration of 46,000 suns than at the irradiation of one sun. Spectrum tuning has an effect of less than 1–4% of the absolute. Moreover, ideal efficiencies consider a unity diode factor, infinite shunt resistance, zero series resistance, 100% photon absorption, and no recombination due to material chemistry and defects. These parameters are far from ideal in real life. (Kurtz et al., 2008).

MJSC efficiency is also raised in a photovoltaic system by lowering possible losses. Bulk recombination losses are caused by non-radiative recombination, which is hotspotted by impurities, dislocations, and other defects in the semiconductor absorber. Bulk recombination losses can be reduced by ensuring the formation of superior epitaxial layers to reduce the density of defects in each MJSC layer.(García-Tabarés and Rey-Stolle, 2014). Moreover, inverted epitaxial growth, BSF alterations, double heterostructure junction insertion, and lattice matching growth optimization all reduce interfacial recombination loss brought on by lattice mismatching defects. Research on surface passivation layers and double heterostructure junctions is crucial because they reduce surface recombination losses.

(Yamaguchi, 2015).

2.3.2.2 Quantum Dot Solar Cells

Using quantum dots as the primary absorber of photovoltaic material is the main characteristic of a quantum dot solar cell. The maximum thermodynamic conversion efficiency that can be achieved by these solar cells is intended to be increased by as much as 66%. The design intends to replace various bulk materials, such as copper, silicon, cadmium telluride, and more, with quantum dots. They also have adjustable band gaps included. They can disperse across a wide range of energy levels by altering their size. In contrast, the materials selected for bulk materials cause the band gap to be fixed. It is this flexibility offered by quantum dots which makes them really attractive and thereby finds its use in multi-junction solar cells. In essence, these particles are semi-conductive, with a size reduction even smaller than the Exciton Bohr radius. According to quantum mechanical dynamics, unlike the energy found in atoms, the energy within an electron tends to become finite. This is an additional explanation for the term "artificial atoms" being applied to quantum dots. The band gap is defined in accordance with the shaping and alteration of the energy levels that result from changing the sizes of these dots. The best use case for these dots in solar cells is when the band gap is adjusted. They are not yet widely accessible for use in commerce. However, a large number of businesses and commercial service providers have begun utilizing it for solar-powered goods. In terms of the solar industry, these are without a doubt going to be the next big thing.

(Written by Dricus De Rooij Managing Director at Sinovoltaics Group)

CHAPTER 3: FLEXIBLE SUBSTRATES OF FLEXIBLE PHOTOVOLTAICS

3.1 Introduction in Flexible Substrates

The primary material that other materials are applied to is called a substrate. One of the essential components of flexible photovoltaics is a flexible substrate. They can be divided into different categories based on the material they are made of, such as metal, ceramic, and plastic substrate.

3.1.1 Metal Substrate

Because of their versatility, thin metal foils are frequently used as substrates in the production of flexible solar cells. Tall ductility of metals leads to tall adaptability of metal foils. Because of its remarkable warmth and chemical stability, stainless steel is the most widely used flexible metal substrate. Its first documented use for sun-oriented cells dates back to the 1980s, and the examples include cadmium sulfide (CdS)-based sun-oriented cells and hydrogenated undefined silicon (a-Si:H) lean film sun-powered cells. The commercial adaptable solar-powered boards, like the GSHK and Worldwide Sun-based companies' adaptable copper indium gallium selenide (CIGS) sun-oriented boards, are currently connected to the stainless-steel thwart. A roll-to-roll product from the Nanosolar company printed on an inexpensive aluminum alloy thwart is an example of how aluminum alloy foil has been used as a substrate for commercially available flexible solar cells in addition to stainless steel thwarts. Additionally, other metals like titanium (Ti) have been used for a long time to create perovskite solar cells. A titanium dioxide nanowire cluster anode produced on the Ti-foil substrate has been used to achieve a PSC with a control change productivity (PCE) of 13.07%. Nevertheless, the commercialization of this substrate may be unlikely due to the unrealistic expectations of the Ti-foil. The beat terminal of the sun-oriented cell must be optically simple to allow photons to pass through to the active materials because metal thwarts have high optical reflectivity over the obvious range. (Xiaoyue Li, Peicheng Li, 2021)

3.1.2 Ceramic Substrate

In terms of the solar industry, these are without a doubt going to be the next big thing.Glass is the most popular ceramic substrate for solar cells. Glass substrates are resistant to moisture and chemical attacks and exhibit good thermal stability. Glass's flexibility is compromised by its poor ductility, which results in a far smaller safe bending radius than that of a substrate made of plastic or metal foil. Modern glassmaking technology allows glass substrates to be thinner than 100 μm, giving the material exceptional flexibility. Researchers have utilized Willow glass, a flexible glass substrate produced by the Corning Company, to create flexible solar cells. Since 2013, flexible solar cells have been made using flexible glass substrates. For instance, in 2017 B. Dou et al. presented a flexible PSC made of glass with a PCE of 18.1%. Other ceramic substrates, such as zirconia ribbon substrate, have also been developed for solar cells in addition to glass substrate. revealed a copper, zinc, tin sulfide-selenide (CZTSSe) solar cell with a PCE of 11.5% that was made using a flexible substrate based on zirconia.

(Xiaoyue Li, Peicheng Li , 2021)

3.1.3 Plastic Substrate

Plastic (or polymer) substrates have attracted a lot of interest in the field of flexible solar cells due to their low cost and low weight. H. Yoon et al. recently created a perovskite solar cell (PSC) on a polyethylene naphthalate (PEN) substrate with a PCE of up to 19.1%. A plastic substrate's primary drawback is its high permeability to oxygen and moisture, which is detrimental to solar cells. This problem can be resolved by applying barrier layers to the plastic substrate on both sides. Silicon oxide and aluminum oxide, for example, are commonly used as barrier layers on plastic substrates to prevent the infiltration of oxygen and moisture. In order to satisfy the permeability requirement for an optoelectronic device, the plastic substrate usually needs a multi-layer coating. Another drawback of the plastic substrate is its low glass transition temperature, which leads to poor thermal stability. The plastic substrate is therefore inappropriate for solar cells that require the deposition of active semiconductor layers at elevated temperatures, such as silicon or CIGS solar cells. Nonetheless, the plastic substrate works well for low-process-temperature solar cell production, including PSCs and organic/polymer solar cells. Polycarbonate (PC), polyimide (PI), polyethylene terephthalate (PET), and PEN are examples of plastic substrates that are frequently used. (Xiaoyue Li, Peicheng Li, 2021)

3.1.4 Textile Substrate

Weaved cotton/polyester fabric served as the foundation for the cell. It served as both a separator between the two yarn electrodes to avoid electrical contact between them and as a carrier of the cell's components. The developed device's flexibility and seamless integration into the textile matrix were made possible by the substrate's woven textile support. Using an interlining adhesive, three pieces measuring 5 cm by 5 cm each of the cotton-polyester material were laminated together. With the exception of a 10-by-6-mm area surrounding the yarn electrodes, a second, thin layer of thermoplastic polyurethane was fused into the upper portion of the layered cloth. In order to keep the applied electrolyte in the left-out region contained on the applied area only and from spreading too much, the TPU layer was used to make the surface hydrophobic. Owing to its light weight, flexibility, and near-invisibility when fused on the fabric surface, TPU was an excellent material choice for imparting the hydrophobic property on the upper surface of the fabric. Making the surface hydrophobic was also less expensive this way than with other technologies, such as plasma treatment.

The fabric's characteristics were also connected to the layered textile substrate's capacity to confine the electrolyte. These characteristics consist of fabric porosity, yarn density, fabric construction, and material type.

(S. Odhiambo, L. Van Langenhove, in Smart Textiles and their Applications, 2016)

There are several methods for creating textile substrates from yarns or fiber webs, such as knitting, tufting, weaving, and nonwoven formation. Furthermore, techniques like flocking, back coating formation on substrates, and adhesive bonding are used to create composites of textile substrates. Using a loom, two sets of yarns are interlaced during the weaving process, usually at right angles to one another. Weft yarns are inserted into the warp using a shuttle or another insertion method after the warp yarns have been fed into the loom. Tutting is the process of threading yarns through needles, punching them through a tufting primary. The loops created in this way hold the yarns in place while the needles are removed from the backing, and the next tuft is formed in the same way. In a nonwoven formation, a continuous web of interconnected fibers is created by entangling or bonding a web of yarns to neighboring fibers using mechanical or chemical bonding techniques. Two substrates are bonded together to form composites of textile substrates. Combined with an adhesive to create a backed or bonded substrate, or by applying chopped fibers to a substrate coated in adhesive to create a flocked substrate. (Harry L. Needles, Ph.D., Von Moody, in Tufted Carpet, 2004)

The lower embedded energy of textile substrates (53 MJ·m−2) in comparison to conventional glass plates is another benefit. This affects the energy pay-back period, which should be less than the panel lifetime if photovoltaics are to be considered true renewable energy sources. In a modest solar climate, we calculated a pay-back period of 1-2 years for textile-based PV, which is 2.5 times shorter than that of rigid panels of a similar kind.However, there are a few requirements that must be satisfied before using textiles as substrates. For instance, can the textile substrate endure the necessary processing conditions to make it photovoltaic, and can the final solar textile withstand usage-related wear and tear as well as cycles of washing and drying? Will the presence of solar cells compromise any significant visual or physical aspects?

(Xiaoyue Li, Peicheng Li, 2021)

3.1.4.1 Deeping into Textile Substrate Technology

The most recognizable solar arrays in the countryside and on the roofs of homes and businesses are probably the ones that most people are familiar with. These panels are made of glass or polycarbonate plates with connected solar cells applied to them. Even though these solar panels have been successful, they still have a lot of disadvantages. Only flat surfaces are suitable for their attachment. Furthermore, because the plates are heavy, the structures to which they are to be attached need to be sturdy enough to support their weight. Glass plates must also be transported and stored carefully due to their fragility. security, style, and improved performance. They reduce costs and lengthen lifespan by providing protection from UV rays, weathering, and corrosion.

In order to get around these problems, more focus is being placed on creating lighter, more flexible cells that are durable, able to withstand harsh conditions, and require less expensive and material resources to build. There is currently a wide variety of commercial photovoltaic cells available that have been used on thin metal or plastic films. These movies are typically less expensive to make and far lighter. Care must be taken when attaching the films to underlying structures because their thinness may still make them susceptible to fracture during application and construction.

Textiles offer a solution to this issue because they are the most widely used flexible material in daily life. A vast array of textile constructions can be made from woven, knitted, embroidered, and nonwoven materials. These materials, which have been utilized for millennia rather than just centuries, are available in a wide variety of natural and synthetic fiber options. Although they are mostly used for clothing, they have recently seen a lot of technical use in things like sacks, sailcloth, and tents. The use of cloth sails by the ancient Egyptians is believed to have begun around 3000 BC. The fact that textile fabrics can be used as solar cell substrates adds even more versatility to their applications. (Hatch, K.L. Textile Science; West Publishing Company: Minneapolis, MN, USA, 1993.)

The fabrics can be specially made for particular PV applications, or they can be regular fabrics that have been altered to become photovoltaic. Numerous fabrication techniques can be used to create textile fabrics, providing a great deal of flexibility in terms of altering the fabric's shape and characteristics. Numerous markets and applications make use of them. Incorporating sensors into textile fabrics for wearable technology and medical applications is also gaining popularity. The smaller size of electronic devices has made this goal possible. Power for these sensors must be obtained directly from outside sources or via small battery intermediaries.

In any case, it would be ideal if the energy harvester was also incorporated into the textile, and a PV method could provide a way to make this happen. An obvious extension is the use of sensors, batteries, and solar cells together. The lower embedded energy of textile substrates (53

MJ·m−2) in comparison to standard glass plates (150–200 MJ·m−2) is another benefit of using them. This affects the energy pay-back period, which should be less than the panel lifetime if photovoltaics are to be considered true renewable energy sources. In a modest solar climate, we calculated a pay-back period of 1-2 years for textile-based PV, which is 2.5 times shorter than that of rigid panels of a similar kind.

(Lind, A.H.N.; Mather, R.R.; Wilson, J.I.B. Input energy analysis of flexible solar cells on textile, 2015)

CHAPTER 4: ACTIVE SEMICONDUCTOR MATERIALS

4.1 An overview of Semiconductor Technology and their history

Tomas Seebeck, a German physicist, first observed peculiar characteristics of semiconductor materials, such lead sulfur, in 1821. The English physicist Michael Faraday revealed in 1833 that, in contrast to metals, whose resistance rises with temperature, semiconductors' resistance reduced as temperature rose. The British engineer Willoughby Smith found in 1873 that selenium, a semiconductor, has a highly light-sensitive resistance. A selenium photometer was created by Werner von Siemens in 1875, and Alexander Graham Bell employed it for a wireless telephone communication system in 1878. The American scientists John Bardeen, Walter Houser Brattain, and William Bradford Shockley revolutionized electronics and semiconductor devices shortly following their 1947 discovery of a bipolar junction transistor that largely replaced electronic tubes.

Nowadays, silicon is used to make the majority of semiconductor devices. Nonetheless, compound semiconductor-based submicron devices, including those built of gallium arsenide or indium phosphide, are able to successfully compete for uses in microwave and ultra-fast digital circuits. Infrared detectors also use other semiconductors, as mercury cadmium telluride. For power devices that must function in difficult conditions and at high temperatures, silicon carbide, aluminum nitride, and gallium nitride show promise. Photovoltaics and the display sector have found significant uses for hydrogenated amorphous silicon and related chemicals. Heterostructure materials, ternary compounds, and quaternary compounds add yet another significant aspect to semiconductor technology. One of the biggest challenges facing the electronic industry for many years to come is the development of novel semiconductor materials and the application of their special qualities. (Michael Shur, in The Electrical Engineering Handbook, 2005)

4.2 What they do and what is their differences between active and passive semiconductor materials

Electronic components are used to build the tiny electronic circuits found in most devices, which can process information and operate machinery.

Any basic discrete electronic device or physical entity that is a part of an electronic system and is used to manipulate electrons or their related fields is called an electronic component. Numerous electrical terminals or leads are present in electronic components. These leads form a circuit with a specific purpose by connecting to other electrical parts, frequently over wire (for example, an amplifier or radio receiver). Basic electronic components can be integrated into packages such as semiconductor integrated circuits, hybrid integrated circuits, or thick film devices, or they can be packaged discretely as arrays or networks of similar components.

(Ross Aresco ,2024)

Semiconductor devices made of semiconductor materials are known as active components. They provide the circuit with power gain or electric power. Diodes and transistors are common electronic components that carry out "active" functions like signal conversion, rectification, and amplification. Materials with a resistance rate that falls between that of an insulator (rubber, ceramic, etc.) and a conductor (iron, copper, gold, silver, etc.) are known as semiconductors. Examples of such materials are silicon and germanium.

(Ross Aresco ,2024)

Electronic devices that carry out "passive" functions, such as consuming, storing, or releasing electric power, must have passive components. They are limited to absorbing electrical energy, which they can then either store in an electric or magnetic field or release as heat. They are unable to supply electricity or amplify power in an electrical circuit. Coils, capacitors, and resistors are examples of common passive components.

(Ross Aresco ,2024)

Active components in a circuit are devices that transform and inject power or energy into the system. Examples of active components include diodes, transistors, Silicon Controlled Rectifiers (SCR), and integrated circuits. They are capable of providing power gain, such as in amplifiers, and act as energy donors. Additionally, active components can control the flow of current within the circuit. On the other hand, passive components, such as resistors, capacitors, and inductors, use power or energy from the circuit instead of providing it. These components are energy acceptors and are incapable of providing any power gain. Furthermore, passive components cannot control the flow of current in the circuit. (Ross Aresco ,2024)

4.3 Semiconductor Materials that can be used in Solar Cells

There are many different semiconductor materials that are necessary for solar cells in the large field of solar energy. The market is dominated by silicon-based solar cells. They are renowned for being incredibly effective and long-lasting. They are used by almost 95% of the market.

4.3.1 N-Type Semiconductors

Dye-sensitized solar cells, or DSSCs, are semiconductor-based photovoltaic devices that directly transform both natural and artificial (solar) radiation into electric current. In a DSSC, the two functions of light absorption and charge carrier separation and transport are performed by different semiconductors than in conventional systems. A sensitizer attached to the surface of a wide band gap n-type semiconductor absorbs light in a conventional DSSC. Often called aGrätzel cell, this hybrid device was initially introduced to science in 1991 with the groundbreaking work by Brian O'Regan and Michael Grätzel, who described adevice composed of sensitized nanocrystalline TiO2 with a 7.1% power conversion efficiency. DSSCs are arguably the least expensive solar technology on the market right now, and over the past 25 years, their efficiency has steadily increased. 11.9% is the verified efficiency record that Sharp was able to attain. But the best-performing DSSC to date was reported in the literature by Mathew et al. DSSC is an environmentally friendly technology that can generate electricity both indoors and outdoors in a variety of lighting conditions. Given that dye-sensitized solar cells function well even in low-irradiation environments, the technology is far more intriguing than conventional solar cells in these circumstances due to the high efficiencies that can be achieved. (Cavallo, C., Di Pascasio, F, 2017)

Notable honors were bestowed upon the DSSCs and their creator, including the 2010 Millennium Technology Prize—the world's most significant technology prize—and the 2009 Balzan Prize.

(Cavallo, C., Di Pascasio, F, 2017)

4.3.2 Photoanode Materials for *n*-Type DSSC

The main photoanode element of DSCs is semiconductor nanostructured films. The primary issues with DSSCs are their relatively low light-harvesting capacity and charge recombination processes. The photoanode has two functions: it supports the sensitizer and transfers photogenerated electrons from the sensitizer to the external circuit. The photoanode material needs to have a large enough surface area and not absorb visible light in order to achieve the best dye adsorption.

(Cavallo, C., Di Pascasio, F, 2017)

The terms "valence band edge" and "conduction band edge" refer to the top and bottom of the valence band and conduction band, respectively, in semiconductor terminology. The symbols ECB and EVB represent the energy of the conduction band edge and valence band edge, respectively. The band gap (Eg) is the energy difference between these levels. Given that it affects all of the material's most crucial electronic characteristics, the band gap's size is arguably the most significant characteristic of a semiconductor. The excited dye molecules' and the photoanode material's conduction band edges (ECBs) should coincide. A high charge carrier mobility of the photoanode is necessary for the efficient collection of photogenerated electrons. The material's affordability, stability, ease of preparation, and environmental friendliness are further desirable qualities. These are the features that make an ideal photoanode unique.

(Cavallo, C., Di Pascasio, F, 2017)

4.3.3 N-Type Nanostructured Semiconductor for DSSCs

Compared to corresponding bulk materials, nanostructured materials have a significantly larger specific surface area. The behavior of electron transport in nanostructures may also be affected by the size of the nanoscale given a limit to the electron mean free path. We call this the effect of quantum confinement. The quantum confinement effect occurs when a particle is too small to be comparable to an electron's wavelength. By establishing optical confinement or photonic localization through the creation of a photonic band gap, periodic nanostructures—also known as photonic crystals—are shown to be exceptional in the manipulation and control of light.

Nanomaterials' special qualities have drawn a lot of interest and have been thoroughly studied for use in photovoltaic, photocatalytic, electronic, optoelectronic, and sensing devices. It is possible to synthesize metal oxides in their nanoform with a variety of morphologies, including different sizes and shapes, which allows for the manipulation of their properties. (Cavallo, C., Di Pascasio, F, 2017)

In order to stop e− and h+ from recombining, the metal oxides should have a high degree of crystallinity. Ohtani et al. expounded on how the physical characteristics of TiO2 powders, including their crystal structure, surface area, particle size, and surface hydroxyls, significantly influence their photocatalytic activity. Many preparation methods have been developed and used in the literature to produce various morphologies in photoanode materials, including sol-gel, hydrothermal/solvothermal, electrochemical anodization, electrospinni, spray pyrolysis, and atomic layer deposition. Asim et al. provided an overview of the various preparation and deposition techniques applied to the photoanode materials of dye-sensitized solar cells (DSSCs), highlighting both positive and negative aspects so that a researcher could carefully select and refine a particular approach. (Cavallo, C., Di Pascasio, F, 2017)

Perez-Page et al. introduced a number of template-based techniques for shaping nanostructuring. Through template-based syntheses, a range of nanostructured materials are created, including two-dimensional (nanoflakes and nanosheets) and one-dimensional (nanowires, nanotubes, etc.) structures as well as zero-dimensional (nanoparticles). The synthesis of mesoporous TiO2 was first reported by Ying and Antonelli in 1995. The process involved a modified sol-gel method using TIP (titanium isopropoxide) as a precursor.

Later on, a number of methods for creating mesoporous materials have been developed.

Mesoporous titania films in the anatase phase were synthesized and reported by Grosso et al., Yun et al., and Hwang et al. in 2001. Sadatlu and Mozaffar revealed a creative and successful method for creating highly ordered mesoporous metal oxide, along with a straightforward and universal technique.

(Cavallo, C., Di Pascasio, F, 2017)

CHAPTER 5: ELECTRODE MATERIALS

5.1 Electrode Materials for Solar Cells

Thin metals, transparent conducting oxides, transparent conducting polymers, carbon nanotubes (CNTs), graphene, silver nanowires (Ag-NWs), and combinations of two or three of these materials are the primary materials used to create top transparent electrodes.

5.1.1 Transparent conducting oxide (TCO)

Transparent conducting oxides, or TCOs, are the most common electrodes found in flexible solar cells. Up until now, tin-doped indium oxide, or ITO, has been the typical electrode material utilized in the solar cell industry. Magnetron sputtering is a method for producing ITO coated glass on a large industrial scale. Since most molecules used in organic solar cells have a work function of 4.3–4.7 eV, which is not near the LUMO or HOMO levels, many attempts have been made to modify the surfaces of ITO films using techniques like UV-ozone, oxygen plasma, and chemical treatments.

The WF of the ITO electrode has significantly increased after treatments, reaching 4.7–5.0 eV. Notably, Helander created a novel method to greatly increase the WF to above 6 eV using ITO surface chlorination. Many thin-films, such as poly(3,4-ethylene dioxythiophene):polystyrene sulfonic acid (PEDOT:PSS) (WF ~ 5.1 eV) dissolved in solution, have been employed as anode surface modifiers. Transition metal oxides like MoOx, NiO, and WOx have served as buffer layers between the anode and active layers. ZnO and TiOx-based electron-selective layers at the cathode enable efficient electron injection and collection.

Even though ITO is the most widely used electrode, there are still a number of issues that make long-term applications difficult. One major obstacle to the sustainable use of ITO is the world's finite supply of indium. Furthermore, the production of solid state lighting, TVs, cellphones, and other products uses ITO as well, so it competes with solar panel production for ITO supplies. It has been demonstrated that new oxides and ZnO-based compounds, such as Al-doped ZnO (AZO) and Ga-doped ZnO (GZO), can replace ITO. Extensive fabrication techniques, like magnetron co-sputtering, are necessary to deposit high-quality films. (Xiaoyue Li , Peicheng Li ,2021)

5.1.2 Thin Metal Films

High conductivity, thick (>100 nm) metal layers (Al, Ag, and Mg) have been widely employed as reflecting electrodes. Metal films turn semitransparent when their thickness is lowered to less than 20 nm. These incredibly thin metal films have shown promise as an ITO replacement for optoelectronic devices in lab settings. In order to enhance ultra-thin metal films' overall performance in device applications, efforts have been made to increase their conductivity and transparency. In comparison to the ITO device using the same CuPc/C60 active bilayer structure, O'Connor's device, which used a transparent electrode made of Ag with a thickness of 9 nm, demonstrated competitive performance.

(Xiaoyue Li , Peicheng Li ,2021)

Based on the good conductivity of thin metal films, Fan et al. reported a dielectric/thin metal/dielectric (DMD) multilayer structure to achieve high transparency and conductivity simultaneously. It is evident from looking at the structure of DMD electrodes that the two dielectric layers provide the electrode with its high transparency due to surface plasmonic effects and optical interference between the two metal/dielectric interfaces. Electrical conductivity throughout the structure is caused by the intermediate thin metal layer.

Metal sulfides (like ZnS269), organic materials, and metal oxides (like MoOx, ZnO, WO3, etc.) are among the many possibilities for the dielectric layer materials. The inner dielectric layers in these DMD electrode structures typically dictate the carrier injection/collection polarity. DMD electrodes have also been applied with additional base metals. Inorganic solar cells typically use metal grids, which are made up of thin metal lines, as the front contacts.

Solar cells employ a conductive buffer layer to enhance photocarrier harvesting, but patterning metal grids on flexible substrates is difficult. Chen and colleagues presented the design of a hybrid electrode made of PEDOT and Ag for use as a current collector in 2013. This design was then applied to a large-area flexible solar cell in 2014, yielding a PCE of approximately 5.85%. (Xiaoyue Li, Peicheng Li ,2021)

5.1.3. Metal nanowires

Copper, gold, and nickel are examples of metal nanostructures that are believed to make good electrodes. Numerous solution-based processing methods have been created to produce metal nanowire flat films. These methods include brush painting, doctor blade coating, drop casting, spin coating, and spray coating. Following appropriate surface treatment, NWs can disperse well in a variety of solvents. Ag NWs offer superior mechanical and electrical flexibility among all the NWs. In general, metal NW networks require an organic buffer layer (like PEDO : PSS) to planarize their surface in order to function as either cathodes (which collect and inject electrons) or anodes (which collect and inject holes). The buffer layer serves to lower the barrier to interconnection between the electrodes and the active layer.

The overall performance of Ag NW electrode solar cells has been continuously improving. The PCE of the cell with ITO was 2.0% after the inverted solar cell architecture was developed, while the PCE of the inverted cell was 3.5%. Ag NWs networks have a great deal of potential for use as flexible, transparent electrodes because of their remarkable mechanical properties and conductivity. However, a number of issues still need to be fixed. Usually ranging from 1 to 50 μm in length, Ag NWs are too short to maintain network and film integrity. Short Ag NWs have a natural propensity to fracture during deposition. Nanoparticles of carbon Because of their unique mechanical, electrical, and optical characteristics, novel carbon materials such as graphene and carbon nanotubes (CNTs) have drawn significant attention from the scientific and industrial community during the past 20 years. The possible application of carbon nanotubes (CNTs) as electrode materials in flexible solar cells has been the subject of intense debate since the early 2000s. Single-wall nanotubes (SWNTs) and multi-wall nanotubes (MWNTs) are the two main categories of carbon nanotubes (CNTs) according to the number of layers they contain. Both types of CNTs have been employed as transparent electrodes in optoelectronics. SWNTs are more transparent and conductive than MWNTs because of variations in their optical transmittance at the same current density. As a result, SWNTs are becoming the preferred electrodes in many electronic devices, replacing brittle ITO transparent electrodes. The in-plane conductance of a single graphene sheet is high. Metal oxides (MoO3, TiO2, and ZnO) and organic polymers (PEDOT: PSS) are frequently used to alter the graphene interface.

Chemical vapor deposition (CVD) is still the most popular technique for creating large carbonate sheets, despite its high treatment temperature and comparatively high cost. It is an effective method for creating self-assembled nanotubes (SWNs) and graphene films. Some very exciting developments in the production of graphene electrodes and SWNTs have resulted from this technology. Recently, scientists have been trying to create carbonate electrodes in more efficient and less expensive ways.

Two other great concepts for SWNT production are chirality-controlled production and high yield SWNT cloning. Reducing graphene oxide is an alternate, less expensive technique for creating graphene electrodes and provides an excellent means of producing graphene inks or films on a large scale. Unfortunately, most graphene films produced by the reduction method have high sheet resistance in the range of 1 kΩ sq 1 and structural defects due to contact resistances between graphene flakes. To reduce the resistance of the graphene layers for large-scale commercial applications, more research is needed to figure out how to simplify the fabrication and transfer processes of graphene.

(Xiaoyue Li, Peicheng Li ,2021)

CHAPTER 6: DEPOSITION TECHNIQUES FOR SOLAR CELLS COATING

6.1 The meaning of coating

The term "coating" refers to the method of applying an ink layer to a substrate by essentially smearing, pouring, painting, spraying, or pouring it on the surface. Blade coating, spray coating, painting, slot-die coating, curtain coating, and slide coating are a few examples of coating techniques. Compared to traditional methods like spin coating, spray coating methods have a great potential for large scale production with little to no material waste.

Solar panel efficiency is intended to be increased through coating. The coating reduces the solar cells' reflection, increasing their efficiency and enabling them to break down pollutants and self-clean. Dust and dirt are actively repelled by the layer thanks to its anti-static qualities. The antireflective, superhydrophobic coatings have anti-dust, anti-pollution, anti-icing, and anti-fogging properties. All of this may result in increased solar cell efficiency. The coating functions by applying a thin, transparent, hydrophilic coating layer to the PV panel. When sunlight strikes the coating's photocatalyst element, it produces reactive oxygen species (ROS), which interacts with organic materials on surfaces like bacteria and volatile organic compounds. Because of this, the microorganisms and volatile organic compounds (VOCs) break down, and the oxygen compounds react with carbon dioxide and water to become neutral. According to durability testing, the coating has a proven lifespan of more than ten years; newer versions are anticipated to last ten to fifteen years before needing to be reapplied.

(Window Insulation, 2024)

6.2 History of Slot-Die Coating

Slot-die coating has a long history that began in the early 1900s. It started out as an adaptation of the doctor blade coating method, which was widely used to apply thin layers of paint, ink, or adhesive to substrates.

In order to increase the precision and control of the coating process, the idea of slot-die coating was developed. To enable the controlled flow of liquid onto the substrate, a narrow slot or channel was introduced in place of a rigid blade. This made it possible to apply the coating material more evenly and precisely.

As manufacturing technology, industrial applications, and materials science advanced, so did the development and improvement of the slot-die coating technique. Because it provided better capabilities for applying ink onto paper or other substrates, the printing industry was the main user of the technique in its early stages.

Slot-die coating became more well-known over time and was used in a variety of sectors outside of printing. Among many other products, it was used in the manufacturing of adhesives, solar cells, batteries, electronic components, and flexible packaging materials. In order to attain greater control over coating thickness, faster coating speeds, and increased precision, the technique was continuously improved and optimized.

Slot-die coating has drawn more attention recently because of its potential for continuous, large-scale manufacturing processes in sectors like biomedical engineering, electronics, and energy. Applications for the latter have focused on drug delivery systems, among other things. The technique's capabilities are being enhanced by ongoing research and development initiatives, which include the creation of new coating materials, sophisticated control systems, and alternative slot designs. (Infinity PV, 2024)

6.3 Blade, Slot-die and Dip coating

Because blade coating and slot-die coating are compatible with high speed, high volume, and low cost roll-to-roll production, they are well suited for PSC's high volume, scale up, and commercialization. The donor and acceptor can rapidly self-assemble into the required ordered and interpenetrating morphology without the need for centrifugal force during the blade coating process, enabling a power conversion efficiency (PCE) of more than 6%. High concentrations of aggregate or crystallites frequently form during the blade coating process, and blade coating techniques have a lower wet film formation rate than spin coating.

A popular technique for conventional dyeing, dip coating allows for the quick and simple deposition of polymer films over a wide surface. Compared to other spray coating and inkjet print processes, the dip coating process forms films quickly, with a single pass, and with free-pinholes. Unfortunately, the slow natural drying process that forms the dip coated film makes it unsuitable for large-scale production.

(Aziz, F., & Ismail, A. F. 2015)

6.4 Spray coating methods for polymer solar cells fabrication

Since spray coating techniques have no restrictions on substrate estimation or molecular utilization of polymers, they hold great promise for replacing conventional preparation techniques, such as turn coating techniques, and have the potential to generate large scales. The creation of fully shower-coated PSC devices is feasible due to the ability to reach a broad variety of liquids with varying rheologies. In any case, there is a major problem with using splash coating to create PSC, specifically the increased thickness and unpleasantness of the film. (Aziz, F., & Ismail, A. F. 2015)

6.5 Conclusions in Deposition techniques for solar cells coating

A further method of making a fiber conducting is to deposit conductive polymer or metal onto the fiber's surface. Then, it is possible to achieve good conductivity without sacrificing the bulk fiber's qualities. To create so-called filé yarns, precious metal strips are wound around silk yarns; this technique has been practiced for at least 2000 years, if not longer. These yarns were used to make fabrics that were regarded as luxury goods. These days, sputter coating or vacuum deposition are frequently used to create metal coatings. Bulk polymerization with the presence of fibers can deposit conducting polymer from a suspension or solution; however, surface polymerization yields better control.

Once a monomer layer has been adsorbed, it is exposed to an appropriate initiator to undergo polymerization. The degree and consistency of the monomer's adsorption as well as the fibers' resistance to the initiator—which is almost always an oxidizing agent—determine the method's success.

The degree to which the metal or polymer that is deposited sticks to the fibers determines how well the deposition techniques work. For instance, when the fiber is bent, the metal layer—which is substantially stiffer than the underlying fiber—is prone to breaking. As a result, conductivity is lost and the layer's continuity is broken. Furthermore, the fabric's gray or black appearance could not be visually appealing. Similar approaches have also been used to introduce metal particles to impart conductivity; however, metal particles have the potential to eventually abrade the holes in the spinneret used in the extrusion process.

By decreasing reflection, the coating improves efficiency and the solar cells' ability to self-clean and degrade pollutants. The layer's anti-static properties enable it to actively repel dirt and dust. It is essential for improved functionality, surface protection, and aesthetics. They reduce costs and lengthen lifespan by providing protection from UV rays, weathering, and corrosion.

CONCLUSION

Way better than indeed some time recently it is time to investigate all the openings for utilizing sun-based vitality to the greatest of it. Depending on your needs, needs and budget, choosing adaptable sun powered boards can be a awesome step to take advantage of the sun in arrange to work for you. In case you need to utilize sun powered boards, introducing adaptable sun based cells is a quick and by and large talking, an reasonable way to take advantage of the sun. The solidness falls brief of standard unbending sun powered boards, but bounty of the other significant benefits make adaptable sun oriented boards a energetic competitor in the showcaseput.

There are two sorts of adaptable sun based boards. Firstly, thin-film sun-oriented boards featuring photovoltaic fabric arranged on a flexible surface, and a crystalline silicon substitute featuring remarkably thin silicon wafers with some bending ability. Sun-oriented boards made of crystalline silicon are currently more prevalent. In a sense, flexible sun-based boards are only slightly wider than regular sun-based boards. Not only does this allow them to form to curved structures, but it also makes adjustable sun-facing boards extremely lightweight and easy to install on your own

One of the greatest downsides of standard sun powered boards is the tremendous cost. With adaptable sun powered boards, there are single-panel 100-watt choices for less than $200 extending to bigger 350-watt sun powered board frameworks for less than $1,000 in US. As a result of their development, low-load bearing surfaces that are unable to support standard sun oriented boards may find that adaptable sun oriented boards are suitable. Custom sun-facing boards are especially common for RVs, watercraft, and camper-trailers. They can also be used for smaller, more personal projects like a shed or detached garage. These alternatives are moreover simpler to uninstall and take with you if you offer. As tenchnology advances at a relentless pace man must take full advantage of sun-oriented vitality. More productive vitality implies lower costs to families. In the another few a long time it is nearly certain that man will discover the right know-how to get adaptable sun powered cells to build up themselves in the commercial center and dispense with the little drawbacks they have.

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