METALORGANIC MOLECULAR BEAM EPITAXY (MOMBE) TOWARD QUANTUM SHEETS OF NANO COMPOSITE SOLAR CELLS

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ABSTRACT
Facing the challenges of the 3rd generation of solar cells the next photovoltaic nanocomposites must deal with some specific topics due to the approaching global energy crisis. Based on the lately achievements on MOMBE and QD technologies, this paper presents the author’s analytically overview of the worldwide research on the developments in nanocomposite solar cells.

KEYWORDS: solar cells, MBE, MOMBE, quantum dots, nanocomposites, QDs’ Super Lattice

1. INTRODUCTION
Producing efficient solar cells it is a challenge for more than four decades. Presently, there are on-the-shelf available solar systems solutions, but their levels of efficiency in electricity production range from around 10 to 20 percent in the best cases. Facing the near future energy demands of our society, more possible research directions are continuously explored in advanced materials laboratories, these including advanced doping methods for MOMBE or completely different approaches as Quantum Dots.

2. MOMBE TECHNOLOGICAL STATE-OF-ART
Having several decades tradition as deposition technology for semiconductors, the use of ultrahigh vacuum (UHV) growth techniques offers some desirable features: the absence of gas-phase interactions allows the precise control of both thickness and composition beyond what can be achieved by other growth methods, and in addition, the use of substrate rotation produces excellent uniformity of ±1.5% across substrates up to 100 mm in diameter.

These advantages have made molecular beam epitaxy (MBE) the dominant method for growth of a number of semiconductor device structures which require abrupt interfaces and a high degree of compositional control, solar cells structures being among them. Though the use of MBE has led to significant improvement in a number of applications, it still retains a number of disadvantages which limit its applicability. While MBE is ideally suited for the growth of As-containing compounds, it has been less successful for fabrication of structures that require phosphorus, for instance. To address these problems, the replacement of elemental group-III sources with gaseous sources, primarily the metalorganic (MO) compounds commonly used in metalorganic chemical vapour deposition (MOCVD), was initiated, creating a new hybrid technique called metalorganic MBE (MOMBE) or alternatively chemical beam epitaxy (CBE).

Just as MBE and MOCVD have found their greatest use for deposition of compound semiconductors, so the development of MOMBE has been directed primarily toward fabrication of III–V compound semiconductor structures, though it will no doubt be investigated for growth of other materials systems, nano-photovoltaic materials being just one of them.

2.1 DEPOSITION SYSTEM DESIGN
The MOMBE growth apparatus is based on conventional MBE equipment (Fig.1). This system consists of a UHV growth chamber containing liquid-nitrogen cooled cryopanels around the substrate heater assembly and the source flange. The same ports that are
used for conventional cells can be used for gas injector cells (for doping technologies). Though in conventional MBE the growth chamber is often pumped with an ion pump, the large amount of hydrogen generated during growth from the group-V hydrides commonly used in MOMBE precludes its use.

In addition to the main pumping unit, which operates continuously, a supplementary pump may be needed to assist in removal of gaseous species during growth. This is particularly important if the MOs are transported with a carrier gas, because the additional load of the carrier gas may overwhelm the main pumping unit.

2.2 SELECTIVE EPITAXIAL GROWTH

More and more optoelectronic applications require more than one type of device on each chip, necessitating multiple growth/processing cycles. In order to facilitate the processing, it is highly desirable to deposit the additional device structures in selected regions of the wafer, without incurring deposition on the masked portions of the substrate. In the growth pressure regime used in MOMBE, surface catalysis becomes essential for growth to occur.

Fig. 2 Schematic of surface interactions between various As sources and TMAA

In fact, below 550 °C, simply pyrolysis is not sufficient to allow efficient decomposition of the MO sources. The presence of a group-V species is also needed in order to induce decomposition of the group-III source. This effect can be exploited to achieve highly selective deposition since mask materials such as SiNx do not readily catalyze the metal–alkyl sources and thus remain free of growth during deposition on the unmasked region. However, even in MOMBE, selective growth can be problematic unless high growth temperatures are employed. Unfortunately, such high temperatures can lead to degradation of the original device structure. Therefore, schemes which allow selectivity at low temperatures are desirable.

2.3 MOMBE PROMISES

MOMBE is a promising method for deposition of III–V materials. For both GaAs- and InP-based materials, well confined n- and p-type doping profiles can be achieved with excellent doping and thickness uniformity using gaseous precursors. While further improvements in the source chemistry are desirable, particularly in the area of gallium precursors for use with TMI, the present technology is acceptable for most types of devices.
Though less developed, initial results are promising as well for other III–V materials. Growth of GaSb and AlSb, for example, has been demonstrated using both elemental and organic Sb sources. Preliminary evidence shows that stoichiometric material can be deposited at reasonable growth rates using nitrogen beams generated from N\textsubscript{2} as the group-V source and standard gaseous group-III precursors. Further work will no doubt expand the understanding of growth of these materials as well as other materials systems such as II–VI compounds or dielectrics in the near future.

3. ENERGETIC FORWARD: QUANTUM DOTS AND SMART MATERIALS THE FUTURE OF SOLAR ENERGY

More energy from sunlight strikes the Earth in one hour than all the energy consumed on the planet in a year, and world demand for energy is projected to more than double by 2050 and to more than triple by the end of the century. Reactors heated by focused, concentrated sunlight in thermal towers that reach temperatures over 3,000 °C, solar cells that achieve 50% efficiency using nanostructured materials such as quantum dots, all these technologies are predicted to be the reality of solar power by mid-century\textsuperscript{4}.

Recently, worldwide scientists met to examine the challenges to developing solar energy as a competitive energy source and to pinpoint the basic research directions that show promise. The cross-disciplinary group of solar energy scientists spanned academia, national laboratories, government, and industry. Their report identified 13 priority research directions with the potential to produce revolutionary, not evolutionary, breakthroughs in materials and processes for solar energy utilization.

They called sunlight is a compelling solution to our need for clean, abundant sources of energy because it is readily available, free from geopolitical tension, and poses no threat to our environment through pollution or to our climate through greenhouse gas emissions. The technology to bridge the gap between our present use of solar energy and its undeveloped potential defines a grand challenge in energy research. Bridging this gap requires revolutionary breakthroughs that come only from basic research.

Firstly, we must understand the fundamental principles of solar energy conversion and than we’ll be able to develop new materials that exploit them. Regarding this approach, there is considerable common ground underlying the three conversion routes of sunlight to electricity, fuel, and heat. Each follows the same functional sequence of capture, conversion, and storage of solar energy, and they exploit many of the same electronic and molecular mechanisms to accomplish these tasks.

A major challenge is tapping the full spectrum of colors in solar radiation. The absorbing materials in the current generation of photocells and, artificial photosynthetic machines typically capture only a fraction of the wavelengths in sunlight.

Designing composite materials that effectively absorb all the colors in the solar spectrum for conversion to electricity, fuel, and heat would be a crosscutting breakthrough. Then the captured solar energy must be transported as excited electrons and holes from the absorber to chemical reaction sites for making fuel or to external circuits as electricity.

Nature transmits excited electrons and holes without energy loss through sophisticated assemblies of proteins whose function we are just beginning to understand with genome sequencing and structural biology.

Today's rapid advances on the scientific frontiers of nanoscience and molecular biology provide a strong foundation for future breakthroughs in solar energy conversion. A host of new materials to replace silicon are now under investigation, including inexpensive plastic photocells, thin polycrystalline films, organic dye injectors, and quantum dots.

The vast majority of solar panels today are made of silicon. These devices are called first generation, and make for highly stable and efficient solar cells, but, because of the material processing necessary, it is expensive to make first generation solar cells and levels of efficiency in electricity production range from around 10 to 20 %.
A more recent alternative involves constructing solar cells using thin films with the potential to produce solar energy at a reduced cost. These thin film cells are called second generation, and are cheaper, but they have more difficulty absorbing radiation and are not very efficient.

Fig.3 An electronic circuit fabricated on a flexible plastic substrate

(Photo courtesy Georgia Tech)

Fig.4 Flexible solar cell on polymeric support

Scientists have been seeking a third generation - a low cost semiconductor material that would have a tunable bandgap, allowing the manufacturer to control the absorptive properties of the solar cell. Quantum dots appear to fill the bill. Quantum dots are a special kind of semiconductor. They are nanoparticles made from a semiconducting material. They range in diameter from 2-10 nm. At this small size many of the bulk properties of materials are not the same. For example the band gap and energy levels of electrons can be altered. As semiconductors with changable band gaps and energy levels they are very useful in other applications. Semiconductors will only conduct electrical charge if acted upon by an external source and quantum dots can be suspended in liquid solutions. This makes them useful in areas including biomedical imaging and security applications. Quantum dots are made from semiconducting materials where elements from two different families are combined.

Fig.5 Isosurface of the 20 nm cubic InAs quantum dot

Fig.6 Contour plots of 2D slices through the ground state electron wavefunction of the 20 nm cubic InAs quantum dot
Quantum dots offer tunable optical and electronic properties that can work around the natural limits of traditional semiconductors. They could form the basis of new computers, and they could be useful as the basis of new solar electric cells.

A quantum dot (QD) is a particle of matter so small that the addition or removal of an electron changes its properties in some useful way. Accordingly, all atoms are, of course, quantum dots, but multi-molecular combinations can have this characteristic. In biochemistry, quantum dots are called redox groups. In nanotechnology, they are called quantum bits or qubits. In the extreme, the position of a single electron in a quantum dot might attain several states, so that a quantum dot could represent a byte of data. Alternatively, a quantum dot might be used in more than one computational instruction at a time. Other applications of quantum dots include nanomachines, neural networks, and high-density memory or storage media.

Quantum dots are especially exciting for their tunable absorption wavelength, their quantum conversion efficiency above 100% through multiple-exciton generation, and their easy fabrication through self-assembly. Quantum dots can be made into flexible sheets, put into liquid form, or made to be transparent, and they cost relatively little compared with bulk silicon semiconductor material and thin films.

Theoretically, quantum dots can achieve the third generation goal of greater than 60% efficiency at $100/m^2$ of paneling, or less; that would be necessary to make photovoltaic solar cells economically competitive with other forms of energy.

Of course, the next defining challenge in QDs use would be the appropriate settlement of the assembling pattern and technology for each type of application. It is already known that the imposition of a superstructure on a given lattice makes the controlled fabrication of structures with chosen properties possible, as QDs can form characteristic patterns as QDSL, exhibiting flat-band ferromagnetism (fig.9).
4. CONCLUSIONS

Consequently, taking into consideration the wide area of possible assembly techniques of QDs on a next generation solar cell element, the selection of a multifunctional method it would be extremely useful. It would allow both the capturing the entire wavelengths from the sunlight through different types of QDs from the solar cell's surface and - through an appropriate method for forming QDSLs in a quantum wire network of square and plaquette lattices (fig. 10) – creating superconductive solar cells with unimaginable efficiency in electricity production.

![Fig. 10: Schematic superconductive plaquette dot-lattice](image)

Certainly, both MOMBE and QDs would continue to be developed as possible solutions for the next generation of nanophotovoltaic solar cells, but definitely the most promising and comprehensive solution would be based on QDs as complex, multifunctional approach of the new concept of all-band-superconductive solar cell.

REFERENCES


AUTHORS

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1 MOMBE- Metalorganic Molecular Beam Epitaxy
2 QD- Quantum Dot
3 Molecular Beam Epitaxy (MBE) - crystals growing method using the interaction of overheated crystalline substrates and vapor beams. The process takes place in ultra high vacuum chambers and requires single crystalline substrates and ultra pure vapors. Semiconductor precursor vapors are projected onto the overheated substrate in controlled pressure and temperature conditions, causing continuous crystal growth. This method is mainly used to produce nanometer scale layers and islands and semiconductor devices that integrate these features. By this capability MBE revolutionized the production of optoelectronics devices.
5 QDSL-Quantum Dots Super Lattice