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| RESEARCH ARTICLE

Nanotechnology and Quantum Dot Lasers

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| ABSTRACT

In this paper, we reviewed the recent literature on quantum dot lasers. First, we started with the physics of quantum dots. These nanostructures provide limitless opportunities to create new technologies. To understand the applications of quantum dots, we talked about the quantum confinement effect versus dimensionality and different fabrication techniques of quantum dots. Secondly, we examined the physical properties of quantum dot lasers along with the history and development of quantum dot laser technology and different kinds of quantum dot lasers compared with other types of lasers. Thirdly, we made a market search on the practical usage of quantum dot lasers. Lastly, we predicted a future for quantum dot lasers.

| KEYWORDS

Nanotechnology, quantum dot, laser, Quantum Dot, Semiconductor materials, semiconductor lasers, and MOSFET

| ARTICLE INFORMATION

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1. Introduction

NANOTECHNOLOGY is science, engineering, and technology conducted at the nanoscale, which is about 100 nanomètres. Nanoscience and nanotechnology are the study and application of tiny things. They can be used across all the other science fields, such as chemistry, biology, physics, materials science, and engineering [Hulla, n.d]. The objects often display physical attributes substantially different from those displayed by either atoms or bulk materials. Phenomena at the nanometre scale are likely to be a completely new world. Properties of matter at the nanoscale may not be as predictable as those observed at larger scales [Simona, n.d]. Important changes in behaviors are caused by continuous modification of characteristics with diminishing size and the emergence of totally new phenomena such as quantum confinement. A typical example of this is that the color of the light emitting from semiconductor nanoparticles depends on their sizes. Designed and controlled fabrication and integration of nanomaterials and nano-devices is likely to be revolutionary for science and technologies [John, n.d].

2. Applications of Nanotechnology

Nanotechnology helps to significantly improve, even revolutionize, several technologies and business sectors: information technology, medicine, transportation, energy, food, and biology, among several others. Electronics and carbon nanotubes are units on the point of exchange of chemical elements as a fabric for creating smaller, faster, and additional economical microchips and devices, likewise as lighter, additional conductive, and stronger quantum nanowires [Salama, 2020]. Advances in engineering are deeply tangled with different technologies, several of which have received so much attention. Engineering can have applications for different technologies like gene-editing, additive producing (3-D printing), AI, spacecraft, and quantum computing. Nanotechnology has considerable potential to change people's lives for the good. For example, the fabrication of low-cost, lightweight star plastics that make solar power widely available or nanoparticles that can limit noxious chemical spills and help reduce airborne pollutants technologies, several of which have received so much attention

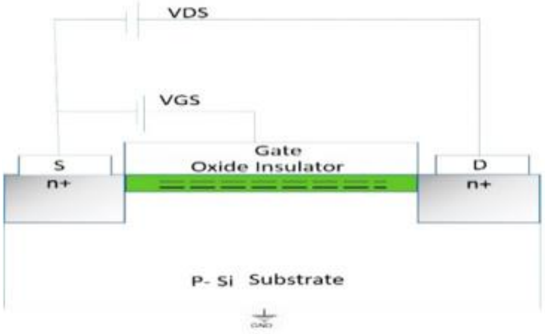

Fig. 1. MOS Structure

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3. Mos Transistor Scaling

One of the main driving forces behind the rapid improvements in integrated circuit products has been the excellent performance and scaling properties of the MOS transistor. By scaling transistor horizontal dimensions, vertical dimensions, and operating voltage, simultaneous improvements in transistor density, switching speed, and switching energy can be realized (Faquir, n.d). For ideal scaling, a reduction in MOS transistor dimensions and operating voltage, along with an increase in silicon dopant concentration, provide transistors with the following improvements: better densities, switching delay time, and switching energy. Also, each generation provides smaller, faster transistors and uses less energy. Fig. 1 shows a MOSFET structure. Another important feature of scaled MOS transistors is the reduction in the amount of energy used during a switching event. Switch energy reduction comes from the mix of lower parasitic capacitance from smaller feature sizes and from lower operative voltage. Negative-channel metal–oxide–semiconductor (NMOS) transistor switching energy is, using transistor gate capacitance and operating voltage.

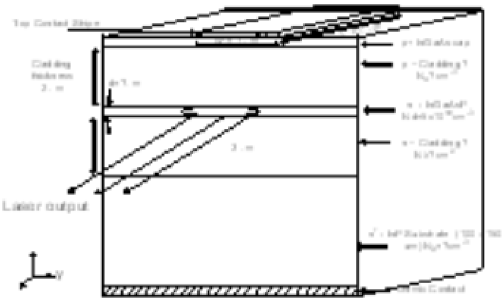

Fig. 2. Laser Structure [4]

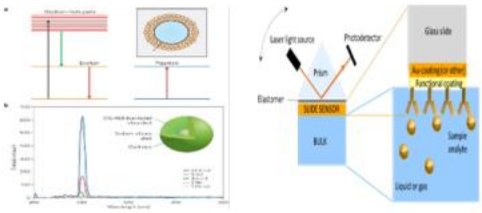

Fig. 3. Classical Surface Plasmon Lasers

Again, this simplified metric leaves out some second-order factors but is useful for estimating generational trends [Christoph, 2020].

3.1 Laser

We need to understand the mechanisms of light emission before we start discussing Light Amplification by Stimulated Emission of Radiation (LASER). As pictured in Fig. 2, light is emitted when electrons belonging to higher energy states make transitions to lower energy states. Not always are the photons emitted. Sometimes electrons fall to lower levels via surface states, collisions, and other scattering mechanisms that are non-radiative. Regardless of the transition type, the emitted photons are spontaneous and thus incoherent. That is, the process of electrons falling to a lower energy level, electron-hole recombination, exciton decay, or changes in vibrational or rotational modes of molecules are spontaneous. Therefore, emitted photons do have a correlation among them. However, in the presence of large photon density, the photons stimulate electrons and holes to recombine, producing photons. This results in stimulated emission. A surface plasmon laser includes a metal layer, a gain medium layer provided on the metal layer, and a circular structure portion in which a whispering gallery mode is generated; surface plasmon light is generated due to surface plasmon resonance on an interface with the metal layer rotating along a circle, and a deformed portion formed to the output part of laser light generated in the circular structure portion of the gain medium layer. This is depicted in Fig. 3.

3.2 Far-Infrared Surface-Plasmon Quantum-Cascade Lasers)

Fig. 4 shows a Quantum-Cascade (QC) laser with various operating wavelengths. The wavelengths were chosen to avoid major phonon absorption bands, which are particularly strong at energies just above the bremsstrahlung band [Jain, 2014].

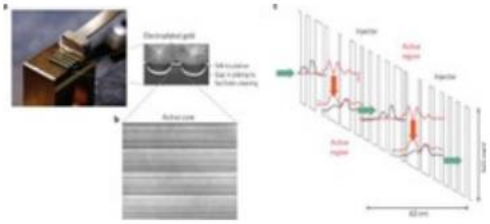

Fig. 4. a, Photograph of a laser bar with four QC lasers (left, courtesy of Frank Wojciechowski) and scanning electron microscopy image of the front facet of a QC laser (right). b, High-resolution transmission electron microscopy image of a QC laser, showing four periods of active regions and injectors. c, Simplified schematic of the conduction band structure for a basic QC laser, where the laser transition is between sub-bands 3 and 2.

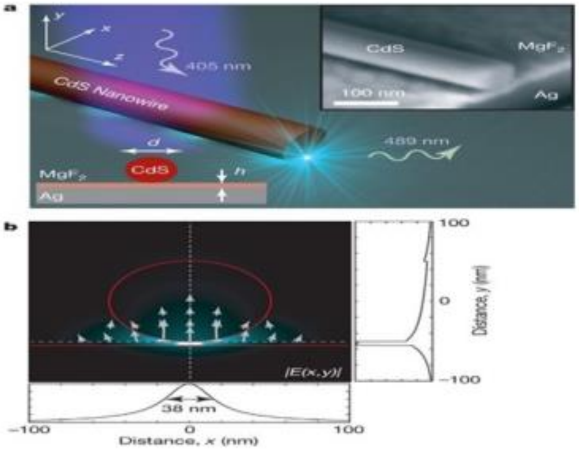

Fig. 5. The deep subwavelength plasmonic laser. (a) the plasmonic laser consists of a CdS semiconductor nanowire on top of a silver substrate, separated by a nanometre-scale MgF2 layer of thickness h. This structure supports a new type of plasmonic mode16, the mode size of which can be a hundred times smaller than a diffraction-limited spot. The inset shows a scanning electron microscope image of a typical plasmonic laser, which has been sliced perpendicular to the nanowire's axis to show the underlying layers. (b) The simulated electric field distribution and direction |E(x, y)| of a hybrid plasmonic mode

3.3 Plasmon Lasers At Deep Subwavelength Scale

An optical source that couples electronic transitions directly to strongly localized optical modes is highly desirable because it would avoid the limitations of delivering light from a macroscopic external source to the nanometer scale, such as low coupling efficiency and difficulties in accessing individual optical modes [Amandeep, 2012], [Alice, 2011] Fig. 5 (a, b).

4. Quantum Dot Laser

After the first cutting-edge results on photons injected lasing in self-organized Quantum dots (QD), a lot of research has followed. Hypodermic injection lasing was first seen in superficial components within GaAs QDs at 95 K and at 70 degrees with limit present densities of 120 and 950 A-cm2, respectively. A higher attribute heat range of the limit present solidity was revealed originally up to 150 K. The limit present solidity stayed relatively great at 70 degrees, and the gadgets usually lase via QD thrilled declares at short and average hole measures. Another accomplishment came from implementing top to bottom combined QDs to heterostructure laser treatment to get over obtain vividness in QDs [Salama, 2019]. This led to constant ground-state lasing in QDs at very low limit present densities.

(60 A-cm2) related to the efficiency of the best QuantumWell (QW) gadgets. Remarkably, top to bottom combined QDs offered an effective way of creating vertical quantum wire-like components allowing polarization control in laser treatment and semiconductor visual amps. In the following period, the limit present solidity at 70 degrees in QD laser treatment was continuously reduced as follows from determined 5 and currently nearing 10.4 A-cm2, and even 6 A-cm2 when recognized by the overall look of triggered exhaust. The gadgets function at the wavelength of 1.22 μm providing 2W of power from a 1.6cm long hole with uncoated aspects [Salama, 2021], [Nathan, n.d]. Length measurements to be 0.25 cm 1. Shorter-wavelength lasers based on QDs formed by sub-monolayer deposits in II-VI and III–V systems were demonstrated to exhibit a high modal gain due to the very high density of the islands. [Salama, 2021]. Presently the highest continuous wave power from a QD laser reached 16W continuous wave (CW) operation per chip at room temperature)). An extremely reliable and temperature-insensitive operation at 1.3 μm up to high temperatures and transmission rates of 10 Gb s-1 was achieved [Salama, 2021] using QD laser wafers from Nano Semiconductor high performance.

5. Applications of QD Lasers

QD laser treatment is progressively increasing the field of applications of the laser. Currently, QD laser treatment takes about a 100% discussion of the gadgets in the spectral variety of 1.15–1.25 μm important for medical devices. In this spectral variety, InP-based laser treatment does not provide good efficiency at wavelengths below 1.3 μm, while the InGaAs QW GaAs-based laser treatment cannot be used at wavelengths above 1.15 μm due to the nasty pleasure of the InGaAs levels [Colombelli, 2001]. Most of the professional success is presently coming from a wide gap in (InGaN–AlInGaN) QD laser treatment. InGaN QDs develop from the natural stage separating impact triggered by the flexible pleasure of the local part stress via mathematical compositional variations permitted at the amazing area. As the III–V materials are known to be stress stable by lattice related to the substrate (in case of layers) or the common lattice parameter (bulk), the chance of the flexible stress pleasure at the amazing area energizes the stage separating impact. The related structure sector components are seen in many III–V materials (InGaP, InGaAlSb, InGaAsP, InGaAsN, etc.) [Barnes, 2003].

6. Future Applications

Ultrahigh material gain and 3D confinement of nonequilibrium carriers in QDs are extremely important for high-speed devices. At first, the high material gain allows us to achieve a higher resonant frequency at lower current densities, thus enabling faster performance at a lower current density, a property vital for device reliability. Then at the same current density, Lasers can provide a much higher operation lifetime by the suppression of the diffusion of nonequilibrium carriers, which causes nonradiative recombination-induced growth of defects. High-speed lasers are particularly important for optical interconnects.

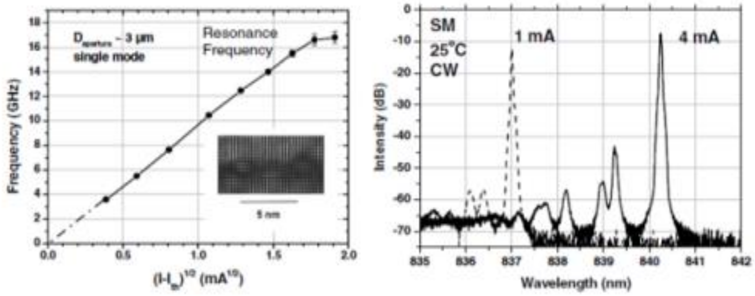

Fig. 6. left: Dependence of the resonant frequency on the square root of the current above the threshold of QD VCSEL right: Electroluminescence emission spectra of the device at different currents

Modern supercomputers already use tens of thousands of vertical-cavity surfaces-emitting (VSEL)- based optical links. Next-generation supercomputers will be based on millions of 25 Gbs-1 VCSEL-based links. Exaflop scale supercomputers are expected to use up to 800 million optical links, with the share of optics approaching 40% of the total system cost (USD 0.5B) and in energy consumption [Gudlavalleti, 2001].

7. Challenges In Nanotechnology and Discussion

Nanotechnology promises significant advances in electronics, materials, biotechnology, alternative energy sources & other applications. Nanocrystals, nanotubes, nanowires, and nanofibers are all next-generation materials. There are many different challenges that also arise with advances in nanotechnology, from technical aspects to ethical ones. So, those who know the technology best (those who design/create it) must ultimately prepare the agenda for broad discussion and participate fully in the creation of relevant policies. In the realm of nanotechnology, public policy and science have almost become inseparable. Nanotechnology emerged from aspirational talks and has taken shape as a major field of research, going since the invention of the scanning tunneling microscope (STM) and atomic force microscope (AFM). The discovery of fullerenes and the invention Carbon Nanotube Tube (CNT) in 1990 became the launching pad of Nanotechnology. Fundamental concerns, synthesizing, and characterization techniques have been discussed for understanding Nanotechnology. After 30 years of the birth of this technology, manufactured nanoproducts have reached around 3,500 and have become available for public use. Scientists worldwide are pursuing the synthesis of nanomaterials with various objectives in almost all-encompassed fields of science, engineering, and technologies. As such, the scope of applications of Nanotechnology is becoming wider and leading it to be more prospective. But in the meantime, some issues on the usage of nano-products have surfaced to be mitigated, thereby causing challenges that scientists, engineers, and technologists would have to face soon.

8. Conclusion

Nanotechnology has been growing its influence in many fields. Some, like Quantum-cascade laser Solar-cell technology, are especially valued, as hundreds of groups around the world pursue more than two dozen approaches using different materials, technologies, and approaches to improve efficiency and reduce costs. To obtain high performance, extensive research work is needed, and it will take some time to realize high-efficiency solar cells containing third-generation concepts. Simultaneously fulfilling the goals of high efficiency, low-temperature fabrication conditions, and good atmospheric ability remains a major technical challenge. Several new works represent a significant leap in overcoming process limitations, increasing the current flow in the cells and thus boosting their overall efficiency in converting sunlight into electricity. Silicon had six decades to get where it is today, and even silicon has not reached the theoretical limit yet. So, the newer technology cannot beat an incumbent in just a few years of development. But it can be clearly seen that quantum dots have a very good potential in solar cells. There is still a long way to go before quantum-dot solar cells are commercially viable, but several milestones have been achieved in recent developments. A green revolution in the renewable energy domain using low-cost QD solar cells is not far from being realized.

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