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Nanoelectronics

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Abstract:

Nano electronics examines the electronic and magnetic properties of systems at the nanoscale. Its subfields include hybrid inorganic-organic electronics, spin electronics and quantum electronics. The specialization in Nano electronics comprises the study of the electronic and magnetic properties of systems with critical dimensions at the nanoscale, i.e. sub ~10 nm. Its key areas include hybrid inorganic-organic electronics, spin electronics and quantum electronics and it combines aspects of Electrical Engineering, Physics, Chemistry, Materials Science, and Nanotechnology.

Increasing miniaturization of devices, component and integrated systems requires development in the capacity to measure, organize and manipulate matter at the nanoscale. This report is a comprehensive, interdisciplinary account of the technology and science that underpin nano electronics covering the underlying physics, nanostructures, nano materials and nano devices.

1. Introduction

Nano electronics refers to the use of nanotechnology in electronic components. The term covers a diverseset of devices and materials, with the common characteristic that they are so small that inter-atomic interactionsand quantum mechanical properties need to be studied extensively. Some of these candidates include: hybridmolecular/semiconductor electronics, one-dimensional nanotubes/nanowires (e.g. silicon nano wires or carbon nano tubes)or advanced molecular electronics.

Nano electronics devices have critical dimensions with assize range between 1nmand100nm. Recent silicon MOSFET (metal-oxide-semiconductor field-effect transistor, or MOS transistor) technology generations are already within this regime, including 22 nanometer CMOS(complementary MOS) nodes and succeeding 14nm,10nm and7nm FET(field-effecttransistor) generations. Nano electronics are some times considered as disruptive technology because present candidates are significantly different from traditional transistors. Nanoelectronics promises to improve, amplify,and partially substitute for the well-known field of micro electronics.The prefix microde notes one millionth and, as applied to electronics, it is used to indicate that the characteristic sizes of the smallest features ofa conventional electronic device have length scales of approximately a micrometer. The prefix nano denotes one billionth.Thus,innano electronics the dimensions of the devices should be asmany as at hous and times smaller than those of microelectronics.

Such a revolutionary advance toward miniaturization of electronics is based on the recently developed ability tomeasure, manipulate, and organize matter on the nanoscale1 to 100 nanometers, i.e., 1 to 100 billionths of ameter. At the nanoscale, physics, chemistry, biology, materials science, and engineering converge toward the sameprinciples and tools, and form new and broad branches of science and technology that can be called nanoscienceandnanotechnology.

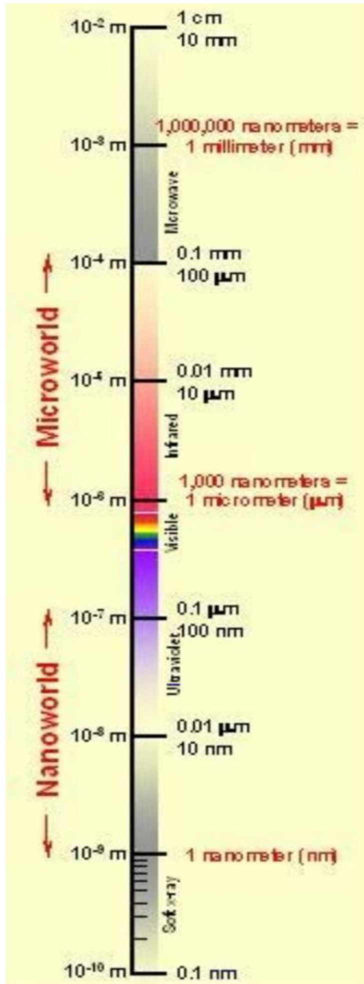
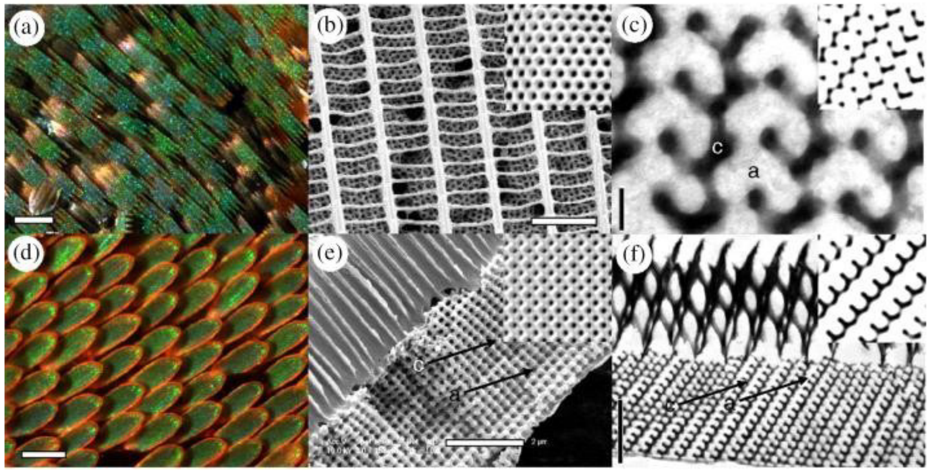


Fig.1.Micro scale to nano scale measurement

Advancing to then an oscale is not just a step toward miniaturization, but requires he introduction and consideration of many additional phenomena. At the nanoscale, most phenomena and processes are dominated by quantum physics and they exhibit unique behavior.Fund a mental scientific advances are expected to be achieved as knowledge in nanoscience increases. In turn, this will lead to dramatic changes in the ways materials, devices, andsystems are understood and created. Innovative nanoscale properties and functions will be achieved through thecontrol of matter at the level of its building blocks: atom-by-atom, molecule-by-molecule, and nanostructure-by-nanostructure. The molecular building blocks of life – proteins, nucleic acids, carbohydrates – are examples ofmaterials that possess impressive properties determined by their size, geometrical folding, and patterns at thenanoscale. Nanotechnology includes the integration of man made nanostructures into larger material componentsand systems. Importantly, within these larger-scale systems, the active elements of the system will remain at then an oscaleificantly different from traditional transistors.

Fig2.Structural colour-producing nano structure in lycaenid(a)-(c)and papilionid(d)-(f)butter flies.



However, the tinier electronic components become, the harder they are to manufacture. Nanoelectronics covers adiverse set of devices and materials,with the common characteristic that they are so small that physical effects alter the material's properties on a nanoscale – inter-atomic interactions and quantum mechanical properties play a significant role in the workings of these devices. At then an oscale, new phenomena take precedence over those that holds way in the macro-world. Quantum effects such as tunneling and atomistic disorder dominate the characteristics of these nano scale devices.

Thefirst transistorsbuilt in 1947 were over 1 centimeter in size;the smallest working transistor today is7nanometers long – over 1.4 million times smaller (1 cm equals 10 million nanometers). The result of these effortsarebillion-transistor processors where,once industry embraces7nm manufacturingtechniques,20billiontransistor-basedcircuitsare integrated intoasingle chip.

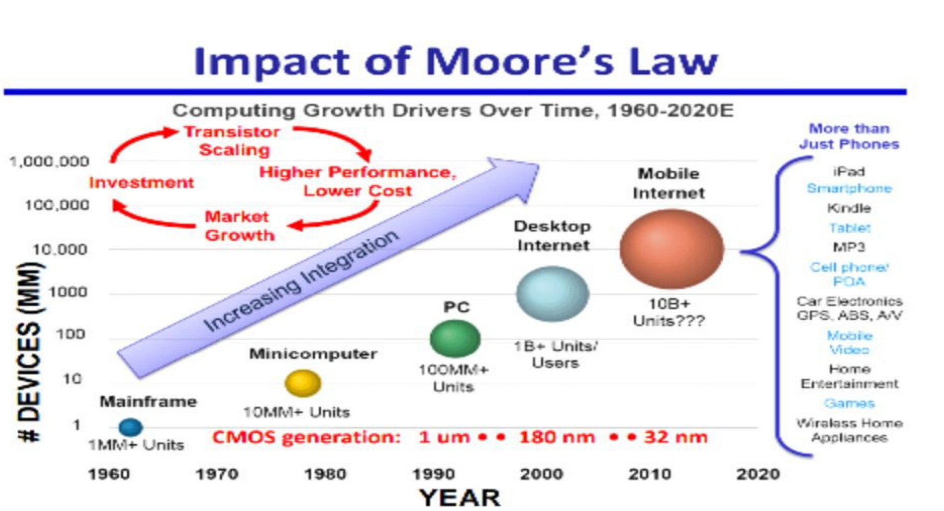
2. Fundamental concepts:-

In1965,Gordon Moore observed that silicontransist or swere under going a continual process of scaling down ward, an observation which was later codified as Moore's law. Since his observation, transistor minimum feature sizes have decreased from 10 micrometers to the 10nm range as of 2019. Note that the technology node doesn't directly represent the minimum feature size. The field of nano electronics aims to enable the continued realization of this law by using new methods and materials to build electronic devices with feature sizes on then an oscale.

2.1 Moore's Law :-

Moore'slawisa1965observationmadebyIntelco-founder Gordon E.Moore that the number of transistors placed in an integrated circuit (IC) or chip doubles approximately every two years. Because Moore's observation has been frequently cited and used for research and development by multiple organizations, and it has been proven repeatedly,it is known as Moore's law.

The observation is named after Gordon Moore, the co-founder of Fairchild Semiconductor and CEO and co-founderof Intel, who in 1965 posited a doubling every year in the number of components per integrated circuit, projectedthis rate of growth would continue for at least another decade. In 1975, looking forward to the next decade, herevised the forecast to doubling every two years, a compound annual growth rate (CAGR) of 41%. While Moore did not use empirical evidence in forecasting that the



historical trend would continue, his prediction held since 1975 and has since become known as a"law."

Fig3.Impact of Moore'sLaw on devices

Moore's law has been a driving force for technological innovation and social change in the late 20th and early 21stcenturies. Moore's law is an observation and projection of a historical trend. Rather than a law of physics, it is anempirical relationship linked to gains from experience in production. Moore's prediction has been used in thesemiconductorindustrytoguidelong-termplanningandtosettargetsforresearchanddevelopment,thus functioning a bit like a self-fulfilling prophecy. Advancements in digital electronics, such as the reduction in quality-adjusted microprocess or prices,the increase in memory capacity (RAM and flash),the improvement of sensors, and even the number and size of pixels in digital cameras, are strongly linked to Moore's law. These step changes in digital electronics have been a driving force of technological and social change, productivity, and economic growth.In dustry experts have not reached a consensus on exactly when Moore's law will cease to apply. Microprocess or architects report that's emi conductor advancement has slowed industry-wide since around 2010,below the predicted byMoore'slaw.However,asof2018,leadingsemiconductormanufacturershavedevelopedICfabricationprocessesinmassproductionwhich areclaimed tokeeppacewithMoore's law.

3. History:-

In 1960, Egyptian engineer Mohamed Atalla and Korean engineer Dawon Kahng at Bell Labs fabricated the first MOSFET(metal-oxide-semi conductor field-effect transistor) with a gate oxide thickness of 100nm,along with a gate length of 20 µm. In 1962, Atalla and Kahng fabricated a nano layer-base metal–semiconductor junction transistor that used gold (Au) thin films with a thickness of 10 nm. In 1987, Iranian engineer Bijan Davari led an IBM research team that demonstrated the first MOSFET with a10 nm gate oxide thick ness, using tungsten-gate technology.

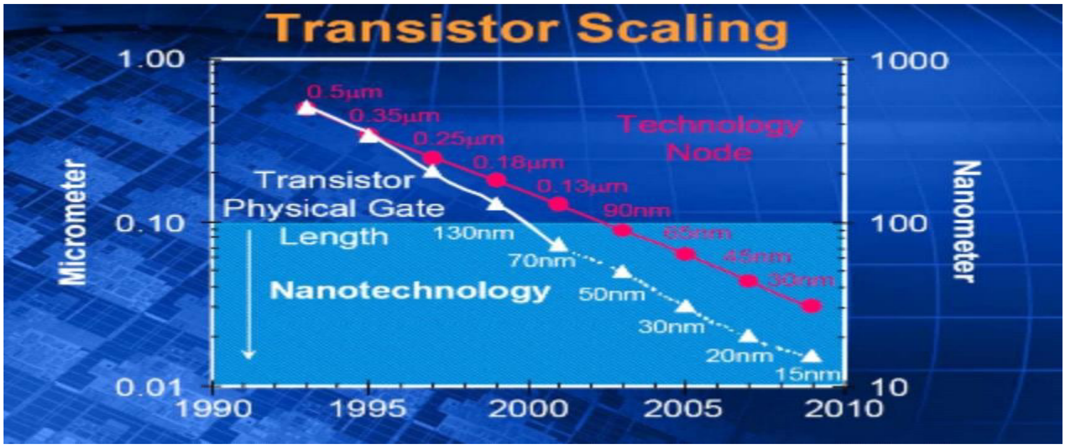


Fig4.Transistor scaling from micrometer to nanometer

In 1999, a CMOS transistor developed at the Laboratory for Electronics and Information Technology in Grenoble,France, tested the limits of the principles of the MOSFET transistor with a diameter of 18 nm (approximately 70atoms placed side by side). It enabled the theoretical integration of seven billion junctions on a €1 coin. However,the CMOS transistor was not a simple research experiment to study how CMOS technology functions, but rather ademonstration of how this technology functions now that we ourselves are getting ever closer to working on amolecular scale. According to Jean-Baptiste Waldner in 2007, it would be impossible to master the coordinatedassembly of a large number of these transistors on a circuit and it would also be impossible to create this on anindustriallevel.

In2006,ateam of Korean researchers from the Korea Advanced Institute of Science and Technology (KAIST) and the National Nano Fab Center developed a 3 nm MOSFET, the world's smallest nano electronic device. It was based on gate-all-around(GAA)Fin FET technology.

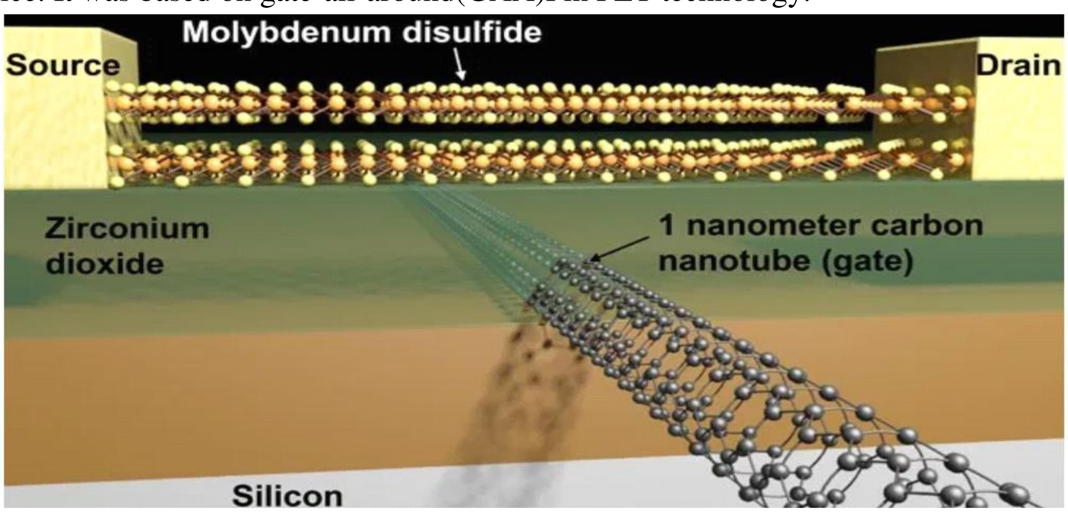


Fig.5. World's smallest transistor till date

Commercial production of nanoelectronic semiconductor devices began in the 2010s. In 2013, SK Hynix begancommercial mass-production of a 16 nm process, TSMC began production of a 16 nm FinFET process,and SamsungElectronics began production of a 10 nm class process. TSMC began production of a 7 nm process in 2017, andSamsungbeganproductionofa5nmprocess in2018.

4. Nano scale Components:-

Nano scale components consist the various components used in the field of Nanoelectronics. Then an oscale components used in nano electronics fallin to two major categories:

1. Inorganic nano crystals
2. Organic molecular components

4.1 Inorganic Nanocrystals :-

The fundamental element of any nano electronic circuitis the devices used to buildit.ForcurrentVLSIsystemstheseinclude silicon transistors and copper wires. For nanoelectronics, it appears that the copper wires will be replacedby either carbon nanotubes(CNT) or silicon nanowires (SNW). The move to CNT or SNW is because they can bechemically assembled at much smaller sizes than copper wires can be patterned with lithography. There are anumberoftechnologiesthatcouldreplacethetransistorasthebasiclogicdevice,theseincludenegativedifferentialresistors,nanowireorcarbonnanotubetransistors,quantumcellularautomata,andreconfigurableswitches.Thesedevices offer sizesofafewnanometers, canbeself-assembled.

4.1.1 Carbon Nano tubes :-

Fig.6. Asinglewallcarbonnanotube

Carbon nanotubes (CNT) are cylindrical carbon molecules (Figure 6) that exhibit unique properties, making thempotentially useful in areas including nanoelectronics, materials, and optics. Their structure gives the nanotubesextraordinary strength, which is attractive for materials use, and can also increase the that make them attractive asnano-electronics wires and devices: they can behave as metallic wires or as semiconductors, depending on theirstructures.

4.1.2 Semiconductingnanowires:-

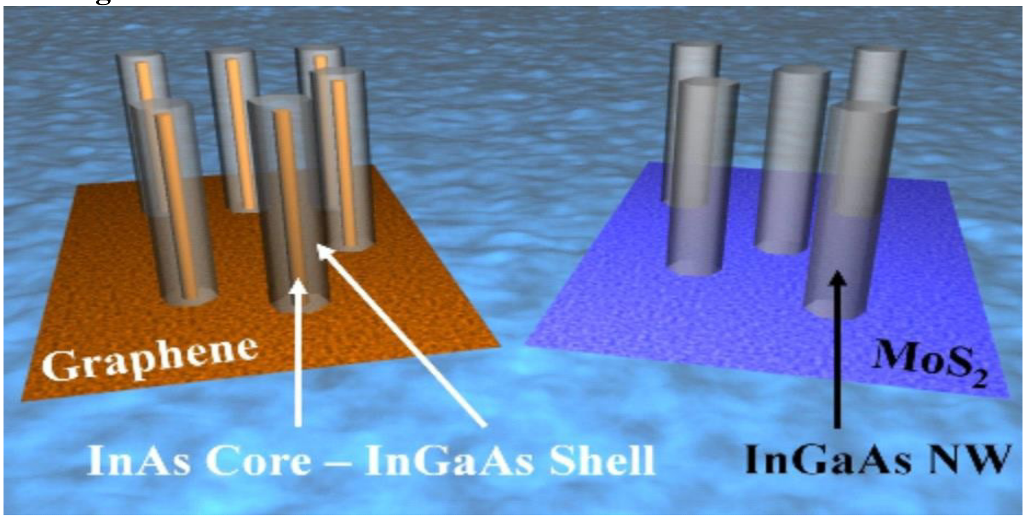


Fig.7.Differentsemiconductornanowires

(NWs),likeCNTs,canbeusedasinterconnectwirestocarrysignalsaswellasbeusedasanactivedevice.Whileone CNT is either an active device or a wire, a single NW can be both an active devices and an interconnect wire. NWsare long thin wires made up of semiconducting materials, such as silicon or germanium that have been fabricatedwith a diameter as small as 3nm and a length of up to hundreds of micrometers. The diameter is about eight timessmallerthanlithographic-based fabricationmethodswilllikelyeverbeabletoachieve.

4.2 Organic Molecular Components:-

Organic molecular components like molecular wires, single molecule, molecular monolayers, and supramoleculeswith different schemes are the contenders from other classes. Organic molecular components are prepared byamalgamation, and therefore less variation is probable in chemical composition and structural parameters. Thereare a large number of molecular species prevailing, possibly personalized for various device applications usingsurface molecular engineering. Single or a few electron transports or transfers include extremely low-energy logicswitchingordatastorage.Molecularnanocomponentshavegreatprospectiveinmanufacturinglow-power,ultradense,andlow-costcomputing chips.

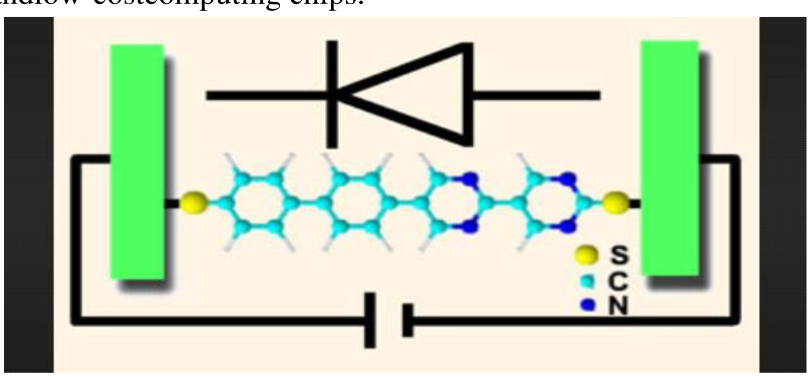


Fig.8.Molecular Diode

Even though NWs and CNTs can be used as active devices as well as wires in nanoelectronics, there is also a set ofmolecules that could be used as the active devices. These molecules behave as diodes or programmable switchesthat can make up the programmable connections between wires. Chemists have designed these carbon-basedmolecules to have electrical properties similar to their solid-state counterparts. Molecular devices have one hugeadvantage over solid-state devices: their size. Thousands of molecules can be sandwiched between two crossingmicro-scale wires to create an active device that takes up very little area. These molecules behave as diode orswitches that makes connection between wires. Current VLSI crosspoints made of pass transistors are 40-100 timeslargerthanawirecrossingorvia.Sincemoleculardevicesfitbetweenthewires,largeareasavingscouldbeachieved.For example, it has been estimated that the use of nanowires and molecular switches could reduce the area of anFPGA by 70% over a traditional SRAM based design at a 22nm process. In addition to being very small, moleculardevices tend to be nonvolatile: the configuration of the molecules remains stable in the absence of electricalstimulation.Inthepresenceofelectricalstimulation,programmablemoleculardevicecanbeturned"on" and"off",whichcanbeused toperformlogic.

4.3 Quantum Dots:-

Quantum dots (QDs) are semi conductor particles a few nanometres in size, having optical and electronic properties that differ from larger particles due to quantum mechanics. They are a central topic in nano electronics. When the quantum dots are illuminated by UV light, an electron in the quantum dot can be excited to a state of higher energy.In the case of a semi conducting quantum dot, this process corresponds to the transition of an electron from the valence band to the conductance band.The excited electron can drop backin to the valence band releasing its energy by the emission of light. This light emission. The color of that light depends on the energy difference between the conduct an ce band and the valence band.

5. Nanomaterials:-

Thesearethematerialwithanyexternaldimensioninthenanoscaleorhavinginternalstructureorsurfacestructureinthenanoscale,withnanoscaledefinedasthelengthrangeapproximatelyfrom1nmto100nm**.**Theyareclassifiedintothree categories:-

1- Zero-dimensional material
2- One – dimensional material
3-Two-dimensionalmaterials

5.1 Zero-dimensionalmaterials:-

Nanomaterials confined in all three dimensions are called nanoparticles, and if they retain their crystal structurethey are called nanocrystals. The spatial confinement of electronic states leads to modifications in band structureand energy levels that are unique to nanoparticles. Although these particles have only been well understood inrecent decades, their use in artistic pursuits is ancient. Metal nanoparticles were used to lend colour to glass, as intheLycurgusCupcraftedinRomeduringthe4thCenturywhichisgreenwhenlightisshoneonthecupfromoutsideandreflectedback(reflectivelight)butredwhenilluminatedfromwithinorbehind(transmittedlight),aphenomenon known as the dichroic effect. Many stained-glass windows also incorporate metal nanoparticles,whose free electrons have a resonant interaction with incident light at certain wavelengths. Controllable andreproducible synthesis of nanocrystals can be achieved either via a 'top-down' method of carving nanocrystals outof larger bulk materials, or a 'bottom-up' method of chemical assembly one atom at a time. Top-down methodsinclude lithography and electrical migration, but these can have major problems with surface roughness anddistortion of the crystal lattice. There are many bottom up methods to create nanocrystals, including chemicalsynthesis, vapour deposition and sol–gel methods. Some of these synthesis methods may deposit a layer on thesurfaceofthesynthesizednanomaterials,whichoftenactsasapassivationlayerpreventingfurtheraggregationandhelpingtokeepthenanoparticlesincolloidalsuspension.Thepassivationlayerischemicallyusefulandcanbetunedto enhance the chemical functionalization of the nanomaterial, adding sensitivity to specific molecules. However,thepassivationlayer canalsoactasasignificantbarrier tocharge transfer.

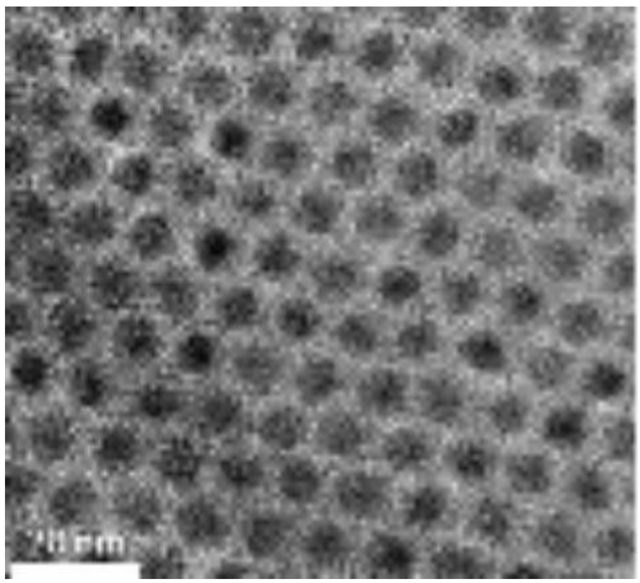


Fig.9. Lead telluride nano crystals in an array,where then anocrystals appears dark

Figureshowsnanocrystalswhichhaveself-assembledintoan arrayimagedusingtransmissionelectronmicroscopy,whereeachindividualnanocrystalappearsdark.Somenanocrystalsappeardarkerthanothersbecausetheircrystallatticeshavedifferingorientationsinthefilm.Theuniquetraitsofnanocrystalsenablemanyusefulapplications.Thewavelengthselectivityofnanocrystalsmakesthemexcellentopticaltagsforbiologicalstudies.Nanocrystalsare smallenoughtoentercellsandsubcellularprocesses,andcanthenbestimulatedtofluorescebyexternallight.They canalsobeusedto convertlighttoelectricityorvice versaas lightemittingdiodes, lasers orsolarcells.

5.2 One-dimensionalmaterials:-

Nanomaterialsconfinedintwoofthethreespatialdimensionsretainsomequantizedpropertiesbutalsohaveabulk dimension. One example is nanowires. These structures can be comprised of metals, semiconductors, insulators oreven polymers or other organic materials. How they are fabricated is strongly material dependent, but similar tonanoparticles, nanowires can either be defined via a top-down lithographic process or assembled in a bottom-upprocess. Chemical synthesis, vapour–liquid–solid deposition and chemical vapour deposition are the most commonbottom-up methods for synthesis. Similar to nanocrystal synthesis. Transmission electron micrograph of leadtelluride nanocrystals in an array, where the nanocrystals appear dark of these nanowire synthesis methods candeposit a surface passivation layer which affects both the chemical and electronic properties of the nanowires. Inaddition to nanowires, which are effectively bulk crystals that are nanoscale along two axes and macroscale alongone axis, another form of one-dimensional nanostructure is the carbon nanotube. Carbon nanotubes, consist of asheet of hexagonally bonded carbon rolled up into a hollow cylinder. Single-walled carbon nanotubes have only asingle layer, and multi-walled carbon nanotubes (which are considerably easier to synthesize) have multiple nestedlayersofcarbon.Nanotubescanbecreatedviaseveralbottom-upprocesses,suchasarcdischarge,chemicalvapourdepositionandhigh-pressurecarbonmonoxidedisproportionation.Thesp2bondingstructureofcarbonnanotubesresults in extraordinary mechanical strength and high thermal conductivity. Electrically, carbon nanotubes can beeither metallic or semiconducting along the tubular axis, depending on the angle of the crystal lattice with respectto that axis. Because of confinement in two dimensions, they exhibit ballistic conduction which leads to very highcurrentdensities.

Nanotube type can be determined spectroscopically, by examining the fluorescence and Raman signature of thenanotubes. Control of nanotube type has been a major focus of research, but there are currently many industriallyavailablehigh-qualitynanotubesofvarioustypes,andtheyaremakingtheirwayintomoreandmoreapplications.

One-dimensional nanostructures such as nanotubes and nanowires are useful for a variety of applications, such asadding mechanical strength tocomposites. Theycan also be used asphotonic waveguidesand collectorsinoptoelectronicgeneratorsandcollectors.However,theyareextremelyinterestingaselectricalcomponents.Nanowires and nanotubes can be individually contacted electrically to create circuit elements that can be used toprobe basic transport physics in a single dimension. They can also be combined to act as networks of elements,exploring percolation thresholds and network topology as they relate to conductivity. A network of nanowires thathasbeenelectricallycontactedinascanningelectron.Sincetheimagewastakenusingchargecarriers,thetechniqueof passive voltage contrast causes the nanowires connected to ground and the probes to appear dark, highlightingthe exact current path through the material. Because one-dimensional nanostructures such as nanowires andnanotubeshaveonenon-confinedaxis,theyprovidebetterconductivitythannanocrystal-basednetworks,althoughsomewhatlessopticaltunability.

5.3 Two-dimensionalmaterials:-

Nanomaterialsconfinedinonlyonespatialdimensionaresheet-likestructuresthatareeffectivelytwo-dimensional.Graphene, a sheet of hexagonally bonded carbon, was the first two-dimensional nanomaterial to emerge, havingbeen accidentally produced for decades before being officially 'discovered' in 2004 by Andre Geim and KonstantinNovoselov.Thecrystallatticestructureofgrapheneisshowninfigure10.Aslewofothertwo-dimensionalnanomaterialshavenowemerged,basedonmaterialssuchasmolybdenumdisulphide(MoS_2),molybdenum diselenide ($MoSe_2$), silicon (Si), germanium (Ge) and boron nitride (BN). Although these materials are effectivelytwo-dimensional,theycanalsobedeformedorfunctionalizedinthethirddimension.

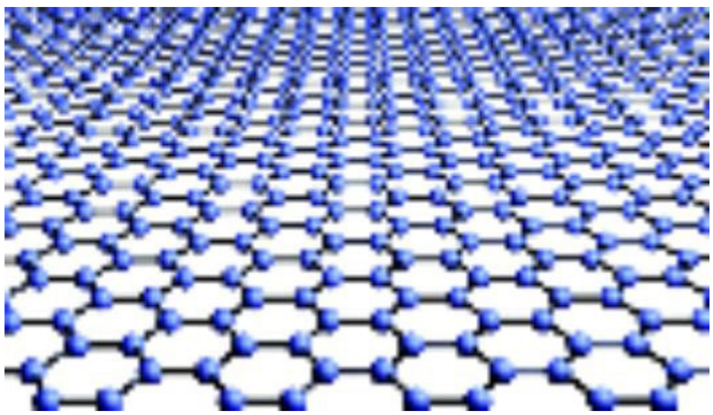


Fig.10.Hexagonalcrystallatticestructure of Graphene

Graphene has a very high mechanical strength, much like carbon nanotubes, as well as good thermal conductivity and a high resistance to gas transfer through its confined axis.Electrically,ithasaveryunusualbandstructure,actingasagaplesssemiconductorwithveryhighelectronmobilitybutnogapbetweentheconductionandvalencebands,andhence limited opticalresponse. Other two-dimensional materials have bandgaps, enabling optical interactions, but lower electrical conductivity.These materials can be produced using a variety of methods, such as exfoliationfrom bulk, chemical vapourdeposition, and sonication and centrifugation in suspension. Many are optically transparent and thus useful fortransparent conductor applications such as graphical displays. They can also be combined into layered composites,with other two-dimensional materials or with one or zero dimensional nanostructures to exploit the properties ofeach.Eachdimensionalityhasdistinct features,but theyallobeydifferentphysicallawsduetotheirnanoscale.

6. Nanoelectronicdevices:-

Currenthigh-technologyproductionprocessesarebasedontraditionaltopdownstrategies,wherenanotechnologyhas already been introduced silently. The critical length scale of integrated circuits is already at the nanoscale (50nmandbelow)regarding thegate lengthoftransistorsinCPUsorRAMdevices.

6.1 Computers:-

Nanoelectronicsholdsthepromiseofmakingcomputerprocessorsmorepowerfulthanarepossiblewithconventional semiconductor fabrication techniques. A number of approaches are currently being researched,including new forms of nanolithography, as well as the use of nanomaterials such as nanowires or small moleculesinplace oftraditionalCMOScomponents.

Field effect transistors have been made using both semiconducting carbon nanotubes and with heterostructuredsemiconductornanowires(SiNWs).

6.2 Memory storage :-

Electronic memory designs in the past have largely relied on the formation of transistors. However, research intocrossbar switch based electronicshave offered an alternative using reconfigurable interconnectionsbetweenvertical and horizontal wiring arrays to create ultra high density memories. Two leaders in this area are Nanterowhich has developed a carbon nanotube based crossbar memory called Nano-RAM and Hewlett-Packard which hasproposedtheuse ofmemristormaterialasafuture replacementofFlashmemory.

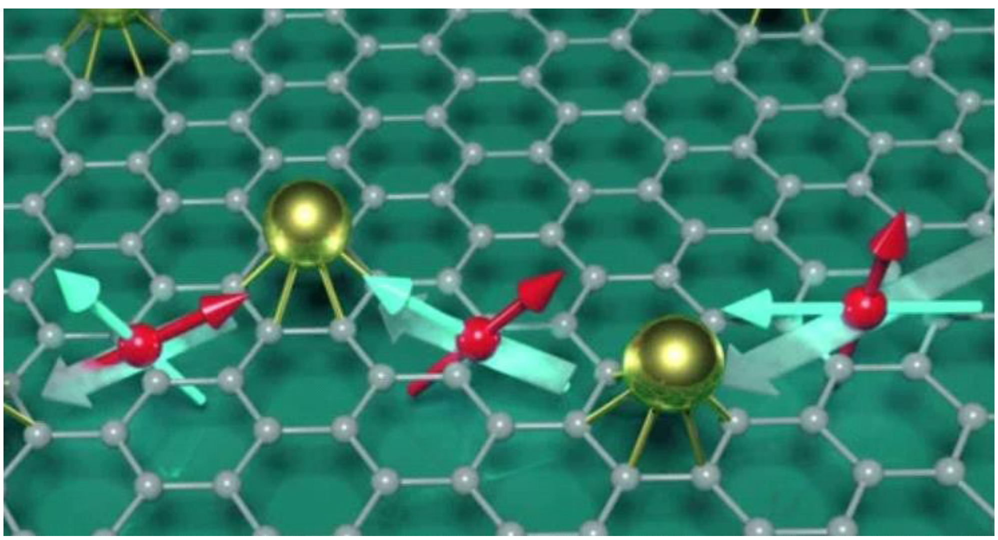


Fig.11.IllustrationofelectronspininaGraphenelattice

An example of such novel devices is based on spintronics. The dependence of the resistance of a material (due tothespinoftheelectrons)onanexternalfieldiscalledmagnetoresistance.Thiseffectcanbesignificantlyamplified for nanosized objects, for example when two ferromagnetic layers are separated by a nonmagnetic layer, which isseveral nanometers thick (e.g. Co-Cu-Co), that has led to a strong increase in the data storage density of hard disksandmadethegigabyte range possible.

6.3 Noveloptoelectronicdevices:-

In the modern communication technology traditional analog electrical devices are increasingly replaced by opticaloroptoelectronicdevicesduetotheirenormousbandwidthandcapacity,respectively.Twopromisingexamplesarephotonic crystals and quantum dots. Photonic crystals are materials with a periodic variation in the refractive indexwith a lattice constant that is half the wavelength of the light used. They offer a selectable band gap for thepropagation of a certain wavelength, thus they resemble a semiconductor, but for light or photons instead ofelectrons.

Quantumdotsarenanoscaledobjects,whichcanbeused,amongmanyotherthings,fortheconstructionoflasers. The advantage of a quantum dot laser over the traditional semiconductor laser is that their emitted wavelengthdepends on the diameter of the dot. Quantum dot lasers are cheaper and offer a higher beam quality thanconventionallaser diodes.

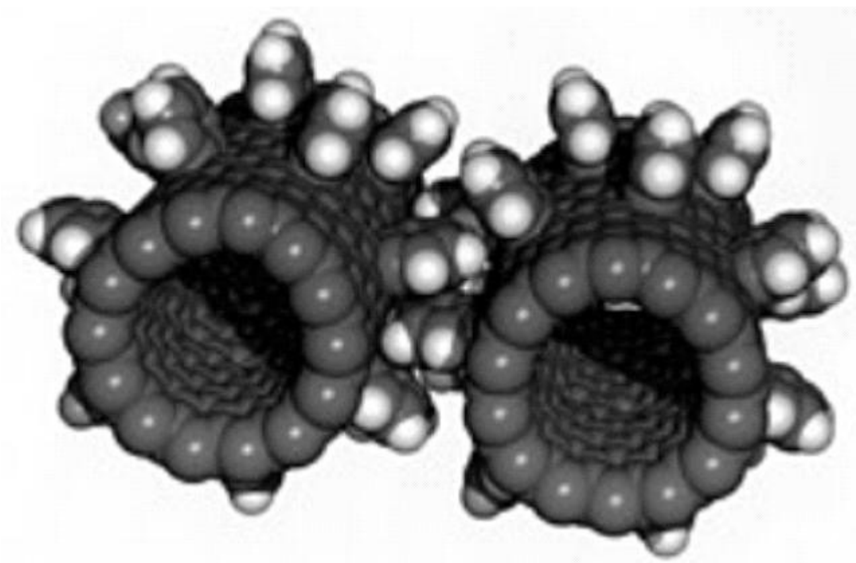


Fig.12. StructureofQuantumDots

6.4 Displays :-

The production of displays with low energy consumption might be accomplished using carbon nanotubes (CNT) orSilicon nanowires. Such nanostructures are electrically conductive and due to their small diameter of severalnanometers, they can be used as field emitters with extremely high efficiency for field emission displays (FED). Theprincipleofoperationresembles thatofthecathoderaytube,butonamuchsmallerlengthscale.

6.5 Quantumcomputers:-

Entirelynewapproachesforcomputingexploitthelawsofquantummechanicsfornovelquantumcomputers,which enable the use of fast quantum algorithms. The Quantum computer has quantum bit memory space termed Qubitforseveralcomputations atthesametime.This facilitymayimprovetheperformanceoftheoldersystems.

6.6 Radios :-

Nanoradioshavebeendevelopedstructuredaroundcarbonnanotubes.

6.7 Energyproduction:-

Researchisongoingtousenanowiresandothernanostructuredmaterialswiththehopetocreatecheaperandmoree fficient solar cells than are possible with conventional planar silicon solar cells. It is believed that the invention ofmoreefficientsolarenergywouldhaveagreateffectonsatisfyingglobalenergyneeds.

There is also research into energy production for devices that would operate in vivo, called bio-nano generators. Abio-nano generator is a nanoscale electrochemical device, like a fuel cell or galvanic cell, but drawing power fromblood glucose in a living body, much the same as how the body generates energy from food. To achieve the effect,anenzymeisusedthatiscapableofstrippingglucoseofitselectrons,freeingthemforuseinelectricaldevice s.Theaverageperson'sbodycould,theoretically,generate100wattsofelectricity(about2000foodcaloriesperda y)usinga bio-nano generator. However, this estimate is only true if all food was converted to electricity, and the humanbody needs some energy consistently, so possible power generated is likely much lower. The electricity generatedbysuchadevicecouldpowerdevicesembeddedinthebody(suchaspacemakers),orsugar fednanorobots.Muchof the research done on bio-nano generators is still experimental, with Panasonic's Nanotechnology ResearchLaboratoryamong those attheforefront.

6.8 Medicaldiagnostics :-

There is great interest in constructing nanoelectronic devices that could detect the concentrations of biomoleculesinrealtimeforuseasmedicaldiagnostics,thusfallingintothecategoryofnanomedicine. Aparallellineofresearchseeks to create nanoelectronic devices which could interact with single cells for use in basic biological research.These devices are called nanosensors. Such miniaturization on nanoelectronics towards in vivo proteomic sensingshouldenablenew approachesforhealthmonitoring, surveillance,anddefense technology.

6.9 Wearable,flexibleelectronics:-

The age of wearable electronics is upon us as witnessed by the fast growing array of smart watches, fitness bandsandotheradvanced,next-generationhealthmonitoringdevices suchas electronic stick-ontattoos.

If current research is an indicator, wearable electronics will go far beyond just very small electronic devices orwearable,flexiblecomputers.Notonlywillthesedevicesbeembeddedintextilesubstratesbutanelectronicsde viceorsystemcouldultimatelybecomethefabricitself.Electronictextiles(e-textiles)willallowthedesignandproduction of a new generation of garments with distributed sensors and electronic functions. Such e-textiles willhave the revolutionary ability to sense, act, store, emit, and move – think biomedical monitoring functions or newman-machineinterfaces – whileideallyleveraginganexistinglow-costtextilemanufacturinginfrastructure.

7. Nanoelectronicsin VLSI :-

In the past decades, VLSI industries constantly shrank the size of transistors, so that more and more transistors canbebuiltintothesamechipareatomakeVLSImoreandmorepowerfulinitsfunctions.Asthetypicalfeaturesize ofCMOSVLSIisshrunkintodeepsubmicrondomain,nanoelectronicsisthenextstepinordertomaintainMoore' slawfor several more decades. Nanoelectronics not only further improves the resolution in traditional photolithographyprocess, but also introduces many brand-new fabrication strategies. Nanoelectronics is also enabling many noveldevicesandcircuitarchitectureswhicharetotallydifferentfromcurrentmicroelectronicscircuits,suchasquantumcomputing,nanowirecrossbarcircuits,spinelectronics,etc.Nanotechnologyisbringinganothertechnologyrevolutiontotraditional CMOSVLSI technology.

Inthepastdecades,VLSItechnologyhasachievedtremendousprogress.BasedonVLSItechnology,computers andinformationtechnologyhavegreatlychangedthe lifestyleofourmodernhumansociety.IntheVLSIindustry,therehas been a constant drive to shrink the size of transistors. In this way, more and more transistors can be integratedinto the same chip area to make VLSI circuit more and more powerful. According to Moore's law, the amount oftransistorsinthesamechipareaisapproximatelydoubledinevery12~18months.Moore'slawhasbeenprovedtogovern the VLSI industry very well in the past decades. The transistor size has been shrunk into deep submicron oreven nanometer domain. Nowadays astate of-the-art Intel Xeon Microprocessor based on 45nm technologycontains 1.90 billion transistors. This has enabled computers to be much faster and more powerful than before. Asthe transistor size continues to shrink, nowadays it is already approaching the bottom physical limit of traditionaloptical photolithography process. The minimum line width of modern microelectronicfabrication process is nowcomparabletotheopticalwavelengthoftheexposurelightusedinthephotolithography.Asaresult,nowadaysVLSIindustry is facing a bottleneck to continue shrinking the size of transistors. In order to maintain Moore's law foranotherseveraldecades,abrandnewtechnology–nanoelectronics,mustbeintroducedintoVLSIindustry.

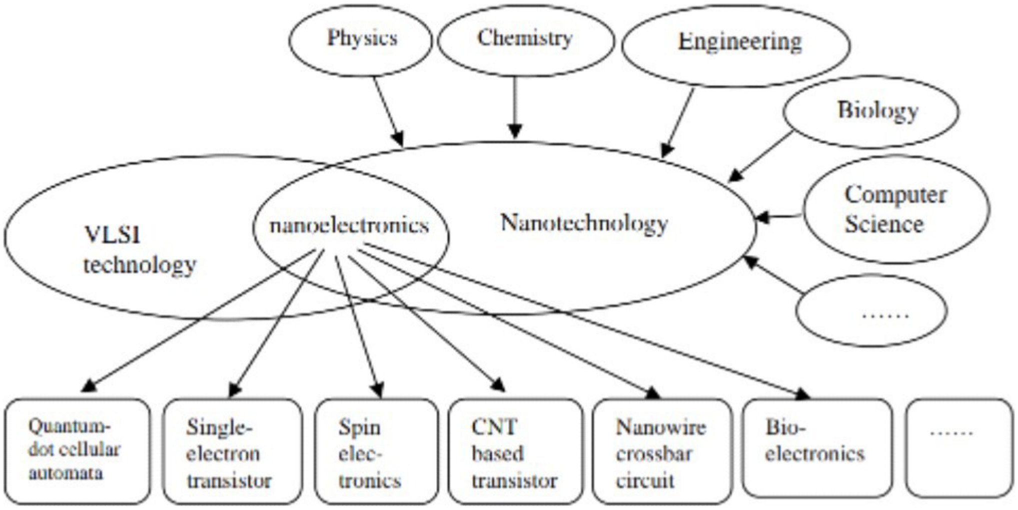


Fig.13.InterdisciplinaryfieldsinNanoelectronics

Asaninterdisciplinarytechnology,nanotechnologyrequiresknowledgeandskillsfrommanydifferentfields,such as physics, chemistry, biology, electrical engineering, mechanical engineering, computer science, etc. Nanoelectronics is an interdisciplinary field between VLSI technology and nanotechnology. Nanotechnology is expected to bring a technical revolution to the current microelectronic VLSI industry. There are many different strategies for future nanoelectronics. For example, nanolithography technologies can be used for the line patterning in VLSI fabrication to achieve resolution in nanometer range. But this strategy still belongs to traditional top-down fabrication strategy. Another category of nanofabrication utilizes individual atoms and molecules to construct nanoelectronics circuits, which belongs to a brand new bottom-up self-assembly strategy. For example, dip-penp nanolithography (DPN) uses nano-ink with individual atoms in it to directly draw pattern on substrate. Other new transistors structures and nanoelectronics circuits based on quantum-dot cellular automata, spin electronics, carbon-nanotube (CNT) based transistors, nanowire cross-bar nanoelectronics circuits, bioelectronics have also been proposed. The fundamental element of any nanoelectronic circuit is the devices used to build it. For current VLSI systems these include silicon transistors and copper wires. For nanoelectronics, it appears that the copper wires will be replaced by either carbon nanotubes (CNT) or silicon nanowires (SNW). The move to CNT or SNW is because they can be chemically assembled at much smaller sizes than copper wires can be patterned with lithography. There are a number of technologies that could replace the transistor as the basic logic device, these include negative differential resistors, nanowire or carbon nanotube transistors, quantum cellular automata, and reconfigurable switches. These devices offer sizes of a few nanometers, can be self-assembled.Nanoelectronics may use totally different architecture from traditional microelectronics circuits, and their working principle may be totally different from current VLSI circuits. Nanoelectronics is bringing another technology revolution to current VLSI industry. As a result, nanoelectronics is bringing new challenges to researchers and the industry will need a large amount of trained engineers to meet the demand for next-generation nanoelectronics. The two emerging technologies in the field of memory storage are spintronics and twistronics.Spintronics is one of the emerging fields for the next-generation nanoelectronic devices to reduce their power consumption and to increase their memory and processing capabilities. Such devices utilise the spin degree of freedom of electrons and/or holes, which can also interact with their orbital moments. In these devices, the spin polarisation is controlled either by magnetic layers used as spin-polarisers or analysers or via spin–orbit coupling. Spin waves can also be used to carry spin. Twistronics is study of how the angle between layers of two dimensional materials can change their electrical properties.

Advantages:-

- Advanced properties of semiconductors can be determined.
- scale Nanoelectronics is also known as "the next step" in the miniaturization of electronic devices, with latest electronics theory and research in the field of nanoelectronics, it is possible to explore the diverse properties of molecules.
- Extreme fabrication also supports the multiple use of single machine. Parallel processing is also empowered by Nanoelectronics.
- Increasing process variability and expected physical and reliability limitations of devices and interconnects.
- Interface and system integration technologies on a single chip and/or integration of different types of chips and devices in a single package.
- Used to produce smaller and faster components.
- Computers consume less energy.
- High speed and high capacity memory.

8. Disadvantages:-

- Allowscircuitstobemoreaccurateontheatomiclevel.Quantumandcoherenceeffects,highelectricfield screatingavalanchedielectricbreakdowns,heatdissipationproblemsincloselypackedstructuresaswell asthe non-uniformity of dopant atoms and the relevance of single atom defects are all roadblocks along thecurrentroadofminiaturization.
- Carriermobilitydecreasesaschannellengthdecreaseandverticalelectricfieldsincrease.
- Wattage/Areaincreasesasdensityincreases.
- Presently,nanoelectronicsisveryexpensiveanddevelopingitcancostyoualot.
- Difficulttomanufactureduetonanosize.

9. FutureAspects:-

- Stretchableelectronicsorflexibleelectronics islikely tobethefutureofmobileelectronics.
- Potentialapplicationsincludewearableelectronicdevices,biomedicaluses,compactportabledevice s,androbotic devices.
- Inthefuture,itislikelythatgraphenewillbecomeadominantmaterialinflexibleelectronics.Graphenei s nothing but an allotrope of carbon that has superb electrical conductivity, flexibility, and physicalstrength.
- Application basedonspintronics.Spintronicsisthestudy of intrinsicspinof electronandit'sassociated magnetic moment.
- Application based on twistronics.Twistronics is study of angle between two semiconductors

layers.

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