

nanotechnology chronological table



- Where Do Nanotechs Come From? Where Are They Going? -

Equivalent to the length of a number of atoms lined up side by side, the nanometer (10⁻⁹m) is the smallest unit of measurement at which an object exhibits inherent characteristics. Nanotechnology (or nanotech for short), a branch of technology involving the observation, manipulation and control of matter on the nanoscale, has undergone dramatic advances in the latter half of the 20th century.

Nanotechnology has led to the development of cell phones and other information technologies, as well as biotechnology such as genetic engineering that are ubiquitous today. Who made the scientific discoveries that led to these technologies and when did they occur? Who was behind the subsequent development of these technologies and what advances will arise in the future?

Working with a number of scientists and technical experts, we have compiled this nanotechnology chronological table and look forward to the unique perspective that each reader will bring to the history of nanotechnology.

1910

1911 Superconductivity discovered by Onnes Nobel Prize
H. K. Onnes of Leiden University, Netherlands, discovers that the electrical resistance of mercury drops to zero near 4°K. He names this condition the superconductive state.

1920

1925 Principle of field-effect transistors first proposed
J. E. Lilienfeld of University Leipzig, Germany, files a patent in Canada for a solid-state electronic device that is considered to be the first field-effect transistor.

1930

1928 Principle of near-field scanning optical microscopes first proposed
E. H. Syngde of Ireland proposes the concept of near-field scanning optical microscopy using a small-aperture probe, thereby pointing out the potential for optical imaging that breaks the diffraction limit.

1932 Electron microscope invented Nobel Prize
M. Knoll and E. Ruska of the Berlin Institute of Technology, Germany, invent the electron microscope.

1935 Langmuir-Blodgett (LB) film discovered Nobel Prize
I. Langmuir and K. B. Blodgett of General Electric Co., USA, discover a technique for depositing monomolecular film from the surface of a liquid onto a solid surface.

1936 Inorganic electroluminescence discovered
G. Destriau of the Institute Curie, France, discovers inorganic electroluminescence.

1940

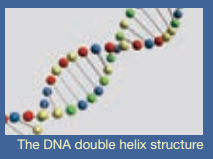
1948 Bipolar transistor invented Nobel Prize
J. Bardeen and W. H. Brattain of Bell Laboratories, USA, invent the bipolar point-contact transistor. Afterwards, W. B. Shockley invents the bipolar junction transistor.

1949 Research on zinc nanoparticles
R. Ueda of Nagoya University, Japan, et al. announce a research on zinc particle using cathode ray diffraction methods. The measured particle size is at the nm level.

1950

1950 Organic semiconductors discovered
H. Inokuchi of the University of Tokyo, Japan, et al. discover the semiconducting properties of organic materials, including violanthrone. This would later lead to the advent of organic electronics.

1953 DNA structure discovered Nobel Prize
J. D. Watson and F. H. C. Crick of Cavendish Laboratory, University of Cambridge, UK, discover the DNA double helix structure.



1954 Semiconductor piezoresistive effect discovered
C. S. Smith of Bell Laboratories, USA, discovers the piezoresistive effect of silicon and germanium semiconductors.

Solar batteries invented
G. L. Pearson of Bell Laboratories, USA, et al. invent solar batteries utilizing p-n junction semiconductors.

Maser concept proposed Nobel Prize
C. H. Townes of Columbia University, USA, and A. M. Prokhorov of Lebedev Institute of Physics, Soviet Union, et al. propose the concept of the maser.

1957 BCS theory announced Nobel Prize
J. Bardeen, L. N. Cooper, and J. R. Schrieffer of the University of Illinois, USA, announce a theory explaining the mechanism of a metallic superconductor.

1959 IC invented Nobel Prize
J. S. Kilby of Texas Instruments and R. N. Noyce of Fairchild Semiconductor Inc., USA, et al. invent the integrated circuit.

Polyacrylonitrile carbon fiber invented
A. Shindo of the Osaka National Research Institute, Japan, et al. invent high strength carbon fiber by carbonizing polyacrylonitrile fibers.

Feynman's Lecture "There's Plenty of Room at the Bottom"
R. P. Feynman of the California Institute of Technology, USA, hypothesizes the arrival and development of science at the atomic level in a lecture at the American Physical Society.

1960

1960 Microelectromechanical systems (MEMS) applied to real-world solutions
I. Igarashi of Toyota Central R&D Labs, Japan, builds a strain gauge that uses the piezoresistive effect. Later, O. N. Tufte et al. of Honeywell Research Center, USA, build a pressure sensor and H. C. Nathanson et al. of Westinghouse Electric, USA, build a resonator using the same effect.

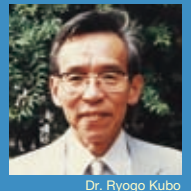
Metal-oxide-semiconductor (MOS) transistor created
D. Kahng and M. M. Atalla of Bell Laboratories, USA, create the silicon MOS transistor.

Successful oscillation of laser
T. H. Maiman of Hughes Research Laboratories, USA, succeeds in oscillating a ruby laser.

Asymmetric cellulose acetate membranes for reverse osmosis invented
S. Loeb and S. Sourirajan of the University of California, USA, invent asymmetric cellulose acetate membranes for reverse osmosis and pave the way for extracting salt from seawater.

1962 Integrated circuit utilizing CdSTFT created
P. K. Weimer of RCA Laboratories, USA, succeeds in creating an imaging device with integrated circuits that utilizes CdSTFT.

1962 Kubo Effect proposed
R. Kubo of the University of Tokyo, Japan, proposes that the properties of nano-sized metal are determined by energy level statistics.



Dr. Ryogo Kubo

Green fluorescent protein (GFP) discovered Nobel Prize
O. Shimomura of Princeton University, USA, et al. discover green fluorescent protein (GFP).

Light-emitting diode invented
N. Holonyak, Jr. of General Electric Co., USA, et al. invent the light-emitting diode.

1963 Complementary metal-oxide-semiconductor (CMOS) invented
F. M. Wanlass of Fairchild Semiconductor Inc., USA, et al. invent CMOS.

Low thresholding of lasers by using heterojunction semiconductor proposed Nobel Prize
H. Kroemer of Varian Inc., USA, and Z. I. Alferov of the Ioffe Physical Technical Institute, Soviet Union, et al. propose the low thresholding of lasers by heterojunction semiconductors.

1964 Kondo Effect proposed
J. Kondo of Electrotechnical Laboratory, Japan, provides an explanation for changes in electrical resistance with temperature as a result of the unusual scattering mechanism of conduction electrons in metal due to magnetic impurities.

1965 Moore's Law announced
G. Moore of Fairchild Semiconductor Inc., USA, predicts future growth rates for large-scale integration (LSI).

1967 Dynamic random access memory (DRAM) invented
R. H. Dennard of IBM, USA, invents the one-transistor one-capacitor DRAM.

Crown ether discovered Nobel Prize
C. J. Pedersen of DuPont Co., USA, discovers crown ether that becomes the foundation for supramolecular chemistry.

1968 Chalcogenide's electrical switch phenomenon and memory phenomenon discovered
S. R. Ovshinsky of USA discovers electrical switch phenomenon and memory phenomenon for Chalcogenide amorphous semiconductors.

1969 Photocatalysis discovered
A. Fujishima and K. Honda of the University of Tokyo, Japan, et al. discover the photocatalyst effect while performing experiments on electrolysis of water.

1970 Semiconductor superlattice concept proposed
L. Esaki of IBM, USA, et al. propose the concept of a semiconductor superlattice.

Charge-coupled device (CCD) invented Nobel Prize
W. Boyle and G. E. Smith of Bell Laboratories, USA, et al. invent the CCD.

Continuous semiconductor laser operation at room temperature succeeds
M. B. Panish and I. Hayashi of Bell Laboratories, USA, et al. succeed in operating a semiconductor laser at room temperature by using a double hetero structure.



The sketch of a fullerene C60 molecule structure that Dr. Eiji Osawa predicted

Fullerene molecule structure predicted
E. Osawa of Hokkaido University, Japan, predicts the structure of a fullerene C60 molecule.

1971 Phase-change memory invented
S. R. Ovshinsky of USA, et al. invent phase change memory.

MPU (Micro processing unit) developed
F. Faggin, M. E. Hoff, Jr., S. Mazor, and M. Shima of Intel, USA, et al. develop the world's first microprocessor (Intel4004).

1972 Amorphous hetero-structure photo-diode created with bottom-up process
E. Maruyama of Hitachi, Ltd., Japan, et al. create the amorphous semiconductor heterodiode Saticon utilizing membranes at nm-level thickness. Also in 1986, K. Tanioka of NHK, Japan, et al. invent the High-gain Avalanche Rushing amorphous Photoconductor (HARP) based on Saticon technology.

DFB lasers first proposed
H. Kogelnik of Bell Laboratories, USA, et al. are the first to propose DFB lasers.

1974 Mode stabilized laser developed
T. Tsukada, R. Ito, and M. Nakamura of Hitachi, Ltd., Japan, et al. develop a semiconductor laser for light communication and information processing.

Concept of Nanotechnology proposed
N. Taniguchi of Tokyo University of Science, Japan, first uses the term "nanotechnology" and proposes the concept.

Quantum states of two-dimensional electron gas analyzed
R. Dingle of Bell Laboratories, USA, et al. analyze the quantum states of two-dimensional electron gas at a heterostructure interface.

Dennard's Scaling Theory proposed
R. H. Dennard of IBM, USA, et al. propose the MOSFET Scaling Theory that afterward becomes the engine for growth in the semiconductor industry.

1975 Amorphous silicon p-n junction created
W. E. Spear and P. G. Le Comber of the University of Dundee, UK, succeed in creating the amorphous silicon p-n junction.

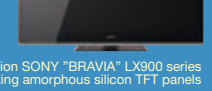
1976 Carbon nanofiber formation observed
M. Endo of Shinshu University, Japan, et al. create and observe nm diameter carbon fiber.

Perpendicular magnetic recording (PMR) proposed
S. Iwasaki of Tohoku University, Japan, et al. propose perpendicular magnetic recording.

Amorphous silicon solar cells proposed
D. E. Carlson and C. R. Wronski of RCA, USA, propose solar cells using amorphous silicon.

1977 Artificial lipid bilayer created
T. Kunitake of Kyushu University, Japan, et al. create the first artificial lipid bilayer, a crucial component of cell membranes.

Intrinsically conducting polymer discovered Nobel Prize
H. Shirakawa of Tokyo Institute of Technology, Japan, et al. discover intrinsically conducting polymer, a plastic that conducts electricity.



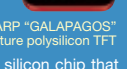
LCD television SONY BRAVIA LX900 series incorporating amorphous silicon TFT panels

1979 Amorphous silicon thin-film transistor (TFT) proposed
P. G. Le Comber of the University of Dundee, UK, et al. propose the amorphous silicon TFT. It becomes the basis for flat panel displays.

Low-temperature polysilicon TFT invented
Y. Shiraki and M. Matsui of Hitachi, Ltd. Japan, et al. invent low-temperature polysilicon TFT on a glass substrate. It contributed to the development of cell phones, digital cameras, and other small information devices.

Artificial molecular machine created
S. Shinkai of Nagasaki University, Japan, et al. synthesize a molecule with a switch function based on the cis-trans isomerization of azobenzenes.

Surface-emitting laser invented
K. Iga of Tokyo Institute of Technology, Japan, et al. invent the surface-emitting laser.



Media tablet SHARP GALAPAGOS storing low-temperature polysilicon TFT

μTAS invented
S. C. Terry of Stanford University, USA, et al. create a gas chromatography and analysis device on a silicon chip that becomes the basis for μTAS.

1980

1980 Amorphous thin film solar battery project begins
A solar battery project focused heavily on amorphous film begins as a strategic project of the Japan's Sunshine Program.

High electron mobility transistor (HEMT) invented
T. Mimura of Fujitsu Ltd., Japan, et al. invent the HEMT.

Thin films for organic electroluminescence proposed
C. W. Tang of Eastman Kodak Co., USA, et al. propose thin films for organic electroluminescence that lead to their practical use today.

Quantum hall effect discovered Nobel Prize
K. v. Klitzing of the University of Würzburg, Germany, et al. discover the quantum hall effect.

1981 Hayashi Ultra-fine Particle Project (1981-1986) begins
The Hayashi Ultra-fine Particle Project begins as an ERATO (Exploratory Research for Advanced Technology) initiative.

Single biomolecule measured
M. Yanagida of Kyoto University, Japan, et al. succeed in measuring a single DNA molecule in solution. In 1984, T. Yanagida of Osaka University, Japan, et al. succeed in measuring a single protein molecule which leads to the direct observation of molecule motors.

1982 Quantum dot proposed
Y. Arakawa and H. Sakaki of the University of Tokyo, Japan, propose the idea of trapping electrons in three-dimensional space (quantum dot).

Scanning tunneling microscope (STM) invented Nobel Prize
G. Binnig and H. Rohrer of IBM Zurich Research Laboratory, Switzerland, et al. invent the STM.

Neodymium magnet invented
M. Sagawa of Sumitomo Special Metals, Japan, et al. invent the neodymium magnet, which remains the strongest magnet in the world.

1983 Dendrimer invented
D. A. Tomalia of Dow Corning, USA, et al. begin systematic research on dendronized polymers that can be used as modules for various functional nanomaterials.

Alkanethiolate self-assembly monolayers produced
R. G. Nuzzo and D. L. Allara of Bell Laboratories, USA, succeed in producing self-assembly monomolecular film through adsorption of alkanethiolate onto metal surfaces.

Automated DNA sequencer proposed
A. Wada of the University of Tokyo, Japan, et al. demonstrate that a genetic sequence can be read with an automatic system.

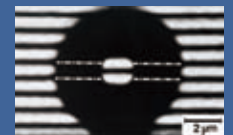
1984 Near-field scanning micro aperture optical microscopy within the visible range developed
D. W. Pohl of IBM Zurich Research Laboratory, Switzerland, et al. and A. Lewis of Cornell University, USA, et al. each develop near-field scanning optical microscopy within the visible range.

Electromagnetic experiments on metal clusters in beams demonstrated
W. D. Knight of the University of California, USA, et al. demonstrate for the first time that electron compositions of metal clusters can be explained with the electron shell model.

Flash memory invented
F. Masuoka of Toshiba Co., Japan, et al. invent flash memory.

Visible photoluminescence discovered in porous silicon
C. Pickering of the Royal Signals and Radar Establishment (RSRE), UK, et al. discover visible photoluminescence in porous silicon.

1985 Fullerene discovered Nobel Prize
H. W. Kroto of the University of Sussex, UK, R. E. Smalley and R. F. Curl of Rice University, USA, et al. discover buckminsterfullerene.



Photograph depicting AB effect demonstrated

1986 Aharonov-Bohm (AB) effect demonstrated
A. Tononmura of Hitachi, Ltd., Japan, et al. demonstrate the AB effect by using a holography electron microscope developed in 1979. This proves the existence of vector potentials.

Atomic force microscope (AFM) invented
G. Binnig of IBM Zurich Research Laboratory, Switzerland, et al. invent the AFM (Atomic Force Microscope).

High-temperature superconductor discovered Nobel Prize
J. G. Bednorz and K. A. Müller of IBM Zurich Research Laboratory, Switzerland, discover the phenomenon where perovskite copper oxides have an electrical resistance of zero and high transition temperatures.

Three dimensional space manipulation of atoms demonstrated Nobel Prize
S. Chu of Bell Laboratories, USA, et al. succeed in trapping an atom in three-dimensional space using laser cooling.

Organic TFT proposed
H. Koezuka of Mitsubishi Electric Co., Japan, et al. propose organic TFT.

Enhanced permeability and retention (EPR) effect discovered
H. Maeda of Kumamoto University, Japan, et al. discover that by regulating the size of DDS (Drug Delivery System) materials, the selective delivery of drugs within a tumor tissue becomes possible.

Drexler's Engine of Creations announced
K. M. Drexler of USA announces his book, *Engines of Creation* and proposes the concept of molecular machines.

1987 New catalytic action of gold nanoparticles discovered
M. Haruta of the Government Industrial Research Institute of Osaka, Japan, et al. reveal their discovery that gold, which had been believed to be chemically inert, actually exhibits excellent catalytic action in nanoparticle form.

Y-type high temperature superconducting material discovered
C. W. Chu of the University of Houston and M. K. Wu of the University of Alabama, USA, et al. discover Yttrium based superconductive material.

Cationic liposome-mediated gene transfection reported
P. L. Felgner of the Palo Alto Research Center, USA, et al. report an efficient method of transferring genes through the use of cationic liposomes.

1988 Bi-type superconducting material discovered
H. Maeda of the Institute for Materials Research, Japan, discovers bismuth-based high-temperature superconductors.

Giant magnetoresistance effect discovered Nobel Prize
A. Fert of the University of Paris-Sud 11, France, and P. Grünberg of Research Centre Jülich, Germany, et al. discover a giant magnetoresistive effect at room temperature using iron/chromium multilayers.

1989 Aono Atomcraft Project (1989-1994)
The Aono Atomcraft Project, which concerns itself with technology to control atoms in single increments, begins in Japan, conducted by Exploratory Research for Advanced Technology (ERATO) of the Japan Science and Technology Agency.

1990 Aberration correction of electron microscope
H. Rose of the Darmstadt University of Technology, Germany, proposes electro-optical system. Afterwards in 1995, M. Haider of European Molecular Biology Laboratory (EMBL), Germany, et al. invent spherical surface aberration correction instrument, which greatly increase the resolution of electron microscopes.

Target treatment of cancer using polymer micelle anticancer drugs developed
K. Kataoka of Tokyo University of Science and M. Yokoyama of Tokyo Women's Medical University, Japan, et al. recognize for the first time the effectiveness of high molecule micelle type cancer medicine in clinical trials with mice.

Atoms controlled with scanning tunneling microscope (STM)
D. M. Eigler of IBM, USA, et al. succeed in controlling atoms with STM. He lines up 35 atoms to form the letters IBM.

1990

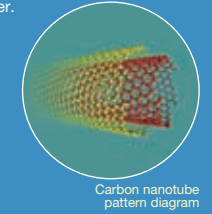
Stealth liposomes isolated
L. Huang and A. L. Kilbanov of University of Tennessee, USA, and G. Cevc of University of Technology, Munich, Germany, et al. isolate stealth liposomes retained in blood circulation with PEGylated liposomes.

1991 Multilayer films formed through self-assembly
G. Decher of Johannes Gutenberg University, Germany, et al. fabricate organic films through a self-assembly process that builds up multiple layers of charged thin films.

High-speed DNA sequencer developed
H. Kambara of Hitachi, Ltd., Japan, et al. develop capillary array high-speed DNA sequencer.

Dye-sensitized solar cell proposed
M. Grätzel of the Swiss Federal Institute of Technology, Lausanne, Switzerland, et al. propose and create the prototype of a dye-sensitized solar cell.

Carbon nanotubes discovered
S. Iijima of NEC Co., Japan, discovers carbon nanotubes and clarifies its structure.



Carbon nanotube pattern diagram

1992 TiC12, a new metal-carbon cluster, discovered
A. W. Castleman, Jr. of Pennsylvania State University, USA, et al. discover a fullerene type metal-carbon cluster molecule, and clarify its catalyst function.

DNA analysis nanodevice developed
R. H. Austin of Princeton University, USA, et al. discover that DNA can be analyzed by a nanodevice made from semiconductor microfabrication technology, which contributes to a large reduction in analysis time.

Apertureless near-field scanning optical microscope invented
S. Kawata of Osaka University, Japan, et al. develop near-field scanning optical microscope with enhanced electric field using plasmon effects through metal nanoprobe.

1994 Colossal magnetoresistance discovered
Y. Tokura of the University of Tokyo, Japan, et al. discover colossal magnetoresistance effects of perovskites. It marks the start of spintronics and the research of strongly correlated materials.

1995 Tunnel magnetoresistance effect
T. Miyazaki of Tohoku University, Japan, et al. discover materials that carry the tunnel magnetoresistance (TMR) effect, which varies electrical resistance greatly at room temperature.

Nano-imprinting first proposed
S. Y. Chou of the University of Minnesota, USA, et al. first propose nano-imprinting.

1996 Nanosheets synthesized
T. Sasaki of the National Institute for Research in Inorganic Materials, Japan, et al. succeed in the synthesis of titanium oxide nanosheets through the monolayer exfoliation of layered titanate.

Nano pore DNA sequencing realized
D. Branton of Harvard University, USA, et al. make possible the high-speed sequential identification of the DNA by measuring slight variations in electric current when passed through nanopores a few nm wide.

2001 MgB2 superconductor discovered
J. Akimitsu of Aoyama Gakuin University, Japan, et al. discover the superconducting properties of MgB2 and confirm that it has the highest transition temperature of non-copper oxides at 39K.

Nano-alloy polymer technology invented
S. Kobayashi of Toray Industries Inc., Japan, et al. develop synthetic alloy material (nano-alloy) made from two high molecules combined at the nano level and based on self-assembled alloy technologies.



A photograph of optical microscope depicting graphene

2004 Graphene successfully isolated Nobel Prize
A. K. Geim and K. S. Novoselov of the University of Manchester, UK, et al. successfully isolate graphene and clarify its electrical properties.

2008 Iron-based layered superconductor discovered
H. Hosono of Tokyo Institute of Technology, Japan, et al. discover iron-based superconducting materials.

Recent projects related to developments of nanotechnology

1992 Japan's National Project on Ultimate Manipulation of Atoms and Molecules begins
Japan's Agency of Industrial Science and Technology starts national project on the study of substances at the atomic and molecular level (1992-2001). It is said to have a great impact on USA and other nations.

2000 National Nanotechnology Initiative (NNI) announced in USA
The US government announces NNI and determines nanotechnology as a national research field. The NNI begins operations in 2001.

2001 The Second Science and Technology Basic Plan designates the field of nanotechnology as a priority area for Japan
Nippon Keidanren (Japan Federation of Economic Organizations) voices the importance of nanotechnology as a priority area. Acknowledged by the government, nanotechnology is included in its national strategy.

2002 First "nano tech" International Nanotechnology Exhibition & Conference held
A nanotechnology exhibition "nano tech" is launched in Japan, and grows into the world's largest nanotechnology exhibition.



"nano tech" exhibition sight

Innovation Support Project established by the Japanese Ministry of Education, Culture, Sports, Science and Technology
The Nanotechnology Researchers Network Center of Japan is established to strategically advance the development of nanotechnology in Japan and to support researchers among industry, government and academia.

EU places importance on nanotechnology
EU places importance on nanotechnology in its Sixth Framework Programme for research and engineering initiatives.

Nanomedicine Research Project established by the Japanese Ministry of Health, Labour, and Welfare
The Ministry of Health, Labour, and Welfare establishes a project to incorporate nanotechnology into medicine. In 2003, the Ministry of Economy, Trade, and Industry launches an advanced nanobiodevice project to develop nanotechnology into biotechnology.

2003 21st Century Nanotechnology Research and Development Act passed in USA
The USA invests 370 million dollars in R&D funds.

2005 Nanomedicine Roadmap Initiative launched by the US National Institutes of Health
The USA launches an initiative to establish eight nanomedicine development centers and to apply nanotechnology in medicine.

National Nanotechnology Initiative, a part of the Council for Science and Technology Policy, launched by the Cabinet Office of Japan
The Cabinet leads unprecedented nanotechnology projects across the agencies and ministries in Japan in nanomedicine devices, nitrogen fuel cells, and nano safety rating projects.

2006 Third Science and Technology Basic Plan established in Japan
The field of nanotechnology/materials is again designated a priority area in the latest Basic Plan of Japan.

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