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Life History of Semiconductors

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Abstract - The history of semiconductors is presented beginning with the first proved observation of a semiconductor effect (Faraday), through the development of the first bias (point- contact rectifiers and transistors, early field- effect transistors) and the proposition of semiconductors up to the contemporary bias (SOI and multi gate bias).
Keywords—band theory, laser, Moore’s law, semiconductor, transistor.

1. Introduction

There’s no mistrustfulness that semiconductors changed the word beyond anything that could have been imagined before them. Although people have presumably always demanded to communicate and reuse data, it’s thanks to the semiconductors that these two important tubes have come easy and take up infinitely lower time than, e.g. at the time of vacuum tubes.

The history of semiconductors is long and complicated obviously, one can not anticipate it to fit one short paper. Give this limitation the authors concentrated on the date they considered the most important and this choice is no way completely unprejudiced. Thus we apologize in advance to all those compendiums who will find that some vital moments of the semiconductor history are missing in this paper.

The rest of this paper is organized in our sections devoted to early history of semiconductors; proposition of their pieces ion the factual bias and a short summary.

2. Early History of Semiconductors

According to G. Busch (1) Alessandor Volta used the term “Semiconducting” for the first time in 1782. The first proved observation of a semiconductor effect is that of Michael Faradsy (1833), who noticed that the resistance of tableware supplied dropped with temperature, which was different than the dependence observed in essence (2). An expansive quantitative analysis of the temperature dependence of the electrical conductivity of AG_2S and Cu_2S was published in 1851 by Johann Hittorf (1).

For some time to come the history of semiconductors focused around two important parcels, i.e. recitation of essence semiconductor junction and perceptivity of semiconductors to light and is compactly is described in subsections 2.1 and 2.2

2.1 Rectification

1874 Karl Ferdinand Braun observed conduction and rectification in essences fides probed with a essence point whisker (3). Although Braun’s discovery was not immediately appreciated latterly, it played a significant part in the development of the radio and discovery of microwave oven radiation in WWII radar system (4) in 1909 Braun participated a Noble Prize in drugs with Marconi.

In 1874 rectification was observed by Arthur Schuster in a circuit made of bobby cables bound by screws a circuit made of bobby cable bound by screws (4). Schuster noticed that the effect appeared only after the circuit was not used for some time. As soon as he gutted the ends of the cables (that is removed bobby oxide), the rectification was gone. In this way he discovered bobby oxide as a new semiconductor (5). In 1929 Walter Schottky experimentally con-concrete the presence of a hedge in an essence semiconductor junction (5).

2.2 Photoconductivity and Photovoltaics

In 1839 Alexander Edmund Becquerel the father of a great scientist Henri Becquerel discovered the photovoltaic effect at a junction between a semiconductor and an electrolyte (6). The photoconductivity in solid was discovered by Willoughby Smith in 1873 during his work on submarine string testing that needed dependable resistors with high resistance (7). Smith experimented with selenium resistors and observed that light caused a dramatic drop of their resistance. Adams and Day were the first to discover the photovoltaic effect in a solid material (1876). They noticed that the presence of light could change the direction of the current flowing through the selenium connected to a club tray (8). Charles Fritts constructed the first working solar cell in 1883. It comported of an essence plate and a thin sub caste of selenium covered with a veritably thin sub caste of gold (8). The effectiveness of this cell was below1 (9).

3. Theory

In 1878 Edwin Herbert Hall discovered that charge carriers in solids are veered in glamorous field (Hall effect). This miracle was latterly used to study the parcels of semiconductors (10). Shortly after the discovery of the electron by J.J. Thomson several scientists proposed theorised of electron grounded conduction in essence. The proposition of Eduard Riecke (1899) is particularly intriguing because he assumed the presence of both negative and positive charge carriers with different attention and mobility’s (1). Around 1908 Karl Baedeker observed the dependence of the conductivity of bobby iodide on the stoichiometry. He also measured the Hall effect in this material, which indicated carriers with positive charge (1). In 1914 Johan Koenigsberger divided solid state accoutrements into three groups with admired to their conductivity essence, insulators and “variable operators” (1). In 1928 Ferdinand Bloch developed the proposition of electrons in structures (10) .In 1930 Bernhard Gudden reported that the observed properties of semiconductors were due simply to the presence of contaminations and that chemically pure semiconductor did not live(1).

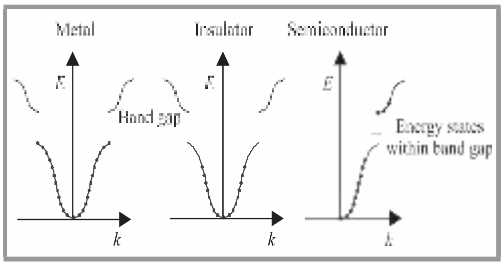

Fig. (a). Alan Wilson's theory of bands in solids.

In 1930 Rudolf Peierls presented the conception of prohibit den gaps that was applied to realistic solids by Brillouin the same time. Also in 1930 Kroning and Penney developed a simple, logical model of periodic eventuality. In1931 Alan Wilson developed the band proposition of solids grounded on the idea of empty and filled energy bands (fig.1) Wilson also verified that conductivity of semiconductor-bluffs was due to contaminations (10). In the same time Heisen berg developed the berg developed the conception of hole which was implicit in the workshop of Rudolf Peierls (10). In 1938 Walter Schottky and Neville F. Mott Nobel prize in 1977 independently developed models of the implicit hedge and dastard rent inflow through a essence semiconductor junction. A time latterly Schottky bettered his model including the presence of space charge. In 1938 Davydov presented a theory of a bobby oxide therapy including the presence of a p-n junction in the oxide, redundant carriers and recombination. He also understood the significance of free countries (11). In 1942 Hans Bethe developed the proposition of thermionic emigration (Nobel Prize in 1967).

4. Devices

4.1 Point-Contact Rectifiers

In 1904 J.C.Bose attained a patent for PbS point-contact cures (12). G.Pickard was the first to show that silicon point-contact cures were useful discovery of radio swells patent in 1906(10) .The selenium and bobby oxide cures were developed, independently in 1925 by E. Presser and 1926 by L.O. Grondahl(10). The selenium cures were heavily used in the WWII in military dispatches and radar outfit (10).

4.2 The p-n junction

During his work on the discovery of radio swells Russel Ohl realized that the problems with cat's whisker sensors were caused by bad quality of the semiconductor. Therefore, he melted the silicon in quartz tubes and let it cool down. The attained material was still polycrystalline but the electrical test demonstrated that the parcels were much more invariant Ohk linked the contaminations that created the p-n junction that he accidentally attained during his technological trials. He held four patents on silicon sensors and p-n junction(13)

4.3 Bipolar Transistor

In1945 William Schockley put forward a conception of a semi-captain amplifier operating by means of the field effect principle. The idea was that the operation of a transverse electric field would Change the conduction of a semi captain sub caste. Unfortunately, this effect was not observed experimentally. Johan Bardeen allowed that this was due to face countries screening the bulk of the material from the field (fig b). His face-proposition was published in 1947(14).

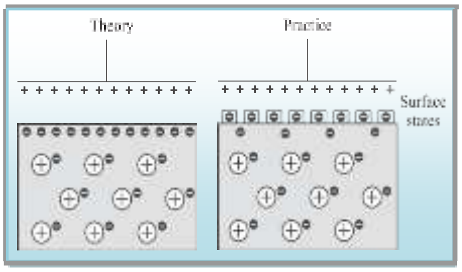

Fig (b) The idea of surface state

While working on the field effect bias, in December 1947 Johan Bardeen and Walter Brattain erected a Germanium point-contact transistor (fig c) and demonstrated that this device displayed a power gain. There was still an query concerning the medium responsible for the transistor action (13). Bardeen and Brattain were induced that face related marvels had the dominant part in the operation of the new device while Shockley favoured bulk conduction of nonwage carriers. About one month latterly he developed a proposition of a p-n junction and a junction transistor(15). Shockley Bardeen and Brattain entered the Nobel prize in drugs in 1956 Jhon Bardeen entered another bone in 1972 for his proposition of superconductivity. In February with the emitter and collector placed on the contrary sides of a veritably thin slice of germanium 0.01cm. This configuration indicated that the conduction was indeed the emitter and collect escarpment along the face would be much longer(15). It was only also that Shockley presented his proposition of transistor operation to the associates (16).

It's worth flashing back that the pivotal parcels of semiconductors at the time were "structure sensitive" as Bardeen put it in , that's they were explosively dependent on the chastity of the sample. The semiconductor escarpment material with which Bardeen and Brattain worked was prepared using a fashion developed by Gordon K. Teal and John B. Little grounded on the Czochralski system. The demitasse was also purified using the zone refining system proposed by William G. Pfann(11).

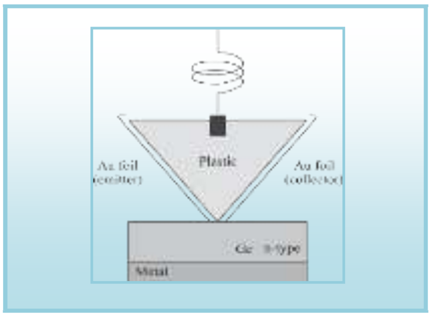

Fig. (c) The first point-contact transistor

Point contact transistors were the first to be produced but they were extremely unstable and the electrical characteristics were hard to control. The first grown junction transistors were manufactured in 1952. They were much better when compared to their point contact precursor but the product was much more delicate. Because of a complicated doping procedure the grown demitasse consisted of three regions forming an n-p –n structure. It had to be cut into individual bias and connections had to be made. The process was delicate and could not be bus slept fluently also, a lot of semiconductor material was wasted. In 1952 diluted junction transistor was reported two bullets of indium were alloyed on the contrary sides of a slice of silicon. Its product was simpler and lower material consuming and could be automated at least incompletely. The attained base range was around 10 m, which let the device operate up to a many MHz only. The first diffused Ge transistor prolixity was used to form the base region; while the emitter was alloyed with, a characteristic “altiplano” shape was reported in 1954. The base range was 1m and the cut-off frequency 500 MHz. It was gene supporter understood that for utmost operations silicon transistors would be better than germanium bones due to lower rear currents. The first commercially available silicon bias grown junction were manufactured in1954 by Gordon Teal. The first diffused Si transistor appeared in 1955. To reduce the resistivity of the collector that limited the operation speed without lowering the breakdown voltage too much John Early allowed of a collector conforming of two layers i.e. high resistivity bone on top of a largely doped bone. A transistor with epitaxial sub caste added was reported in1960. In the same time, Jean Hoerni proposed the planar transistor both base and emitter regions diffused. Herbert Kroemer proposed the oxide that served as a mask was not removed and acted as a passivating sub caste (15) farther enhancement of speed. A erected in electric field could be introduced into the base by means of canted doping. Another way of introducing the electric field in the base he allowed of was grading the composition of the semiconductor material it tone, which redounded in canted band gap. This hetero structure conception could not be put to practice fluently because of fabrication problems (17) .

4.4 **Integrated Circuit**

The transistor was much more dependable worked briskly and generated lower heat when compared to the vacuum tubes therefor it was anticipated that large system could using these bias. The distance between them had still to be as short as possible to minimize detainments caused by interconnects. In 1958 Jack Kilby demonstrated the first intertwined circuit were several bias were fabrication in one silicon substrate and connected by means of line cling. Kilby realized that this would be a dis- advantage thus in his patent he proposed conformation of interconnects by means of deposit of aluminum on a sub caste of SiO_2 covering the semiconductor material (15). This has been achieved singly by Robert Noyce in1959. In 2000, Jack Kilby entered a Noble Prize in drugs for his achievements.

4.5 Tunnel Diode

Leo Esaki studied heavily doped junctions to find out how high the base of a bipolar transistor could be unravelling before the injection at the emitter junction came shy. He was apprehensive that in veritably narrow junction tunneling could take place. He attained the first Ge tunneling diode in 1957 and a silicon one in 1958. Esaki’s donation at the International Conference of Solid State Physics in Electrons and Telecommunication in 1958 was largely appreciated by Shockley and unfortunately, Shockley displayed a complete lack of interest when Robert Noyce came to him to present his idea of a lair diode two times before. As a result, Noyce moved to other system (20). The lair diode was extremely resistant to the environmental conditions due to the fact that conduction was not grounded on nonwage carriers or thermal good also its switching time were important shorter than those of the transistor. Leo Esaki received a Nobel Prize in drugs in 1973 for his work on tunneling and superlatives.

4.6 Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

In 1930 and 1933 Julius Lilienfeld attained patent for devices suggesting moment’s MESFET and MOSFET, respectively. In 1934 Oslar Heil applied for his theoretical work on capacitive control in field effect transistor (3). The first bipolar transistors were relatively unreliable beget semiconductor face was not duly passivized. A group directed by M.M. Atalla worked on this problem and set up out that a sub caste of silicon dioxide could be the answer (23) During the course of this work a new concept of a field effect transistor was developed and the factual device manufactured (24). Unfortunately the device could not match the performance of bipolar transistors at the time and was largely forgotten(15). Several times before Bell Laboratories demonstrated an MOS transistor Paul Weimer and Tokel Wallmark of RCA did work on similar bias. Weimer made transistors of cadmium selenide (11). In 1963 Steven Hofstein and Fredric Heiman published a paper on a silicon MOSFET (25) (fig d). In the same time the first CMOS circuit was proposed by Frank Wanlass (26). In 1970 Willard Boyle and George Smith presented the conception of charge coupled bias (CCD) a semiconductor fellow of glamorous bubbles (27). Both scientists entered a Nobel Prize in drugs in 2009 for their work on CCD.

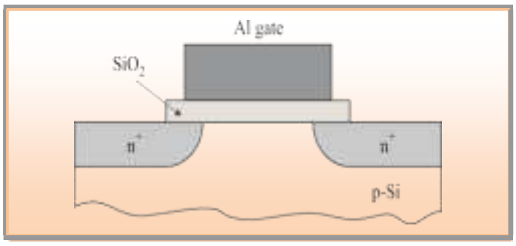

Fig. (d) A metal oxide semiconductor transistor Across section of

Beforehand MOSFETs had aluminium gate. Development of a poly-Si gate(28) led to a tone aligned device, where the gate itself constitutes the mask for source and drain diffusion. In this way parasitic gate-to-source and gate-to-drain capacitances associated with gate imbrication could be controlled. Since polysilicon had high resistance, gates made of silicides of refractory essence were proposed (29). Reduction of the size of device led to the so-called short channel goods (SCE) including threshold voltage roll-off and drain convinced hedge lowering. The way to manage with this problem include a reduction of the depth of source and drain (31) combined with sweats to avoid increased resistance, Smoothly unravel drain(32), elevated source drain(S/D) or conceivably Schottky barrier S/D. Threshold voltage and punch through are controlled by means of applicable doping profile of the channel that makes it possible to maintain fairly good face mobility (35). Short channel goods are considerably reduced when gate oxide is thin. Because of dropped consistence, gate leakage current obviously grows, adding power consumption of the entire chip, which is an undesirable effect for battery powered mobile systems.

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It's estimated that gate leakage current increases approximately 30 times every technology generation, as opposed to 3-5 times increase of channel leakage current(36) piecemeal from leakage current the reduction of gate oxide consistence increases the vulnerability of the device to boron penetration from the poly-Si gate into the channel . A number of different high accoutrements are considerably delved.

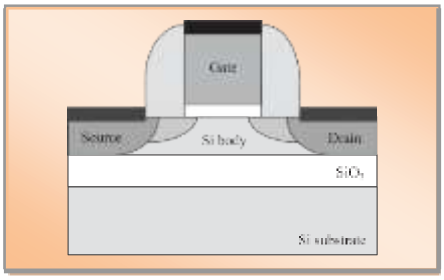

Fig.(e) SOI MOSFET cross section

An intriguing extension of the classical bulk MOSFET is silicon-on-insulator (SOI) see Fig. e (37). The advantage of SOI is the ease of electrical insulator of a device from the rest of the intertwined circuit which increases packing viscosity also the area of source and drain junctions is significantly reduction range is limited by the Si body consistence thus it's extensively believed that SOI helps reduce short channel goods unless source to drain coupling through channel and BOX cannot be neglected. The parcels of SOI bias are bettered with reduction of body consistence. It has believed that completely depleted ultra-thin-body SOI (FD UTB SOI) is one of the stylish scaling results. Due to excellent gate, control of the channel these bias may be un-doped or veritably smoothly unravel. In this way mobility is not degraded and threshold voltage is less dependent on the oscillations of answer concentration (38) fig. f, but this is another story.

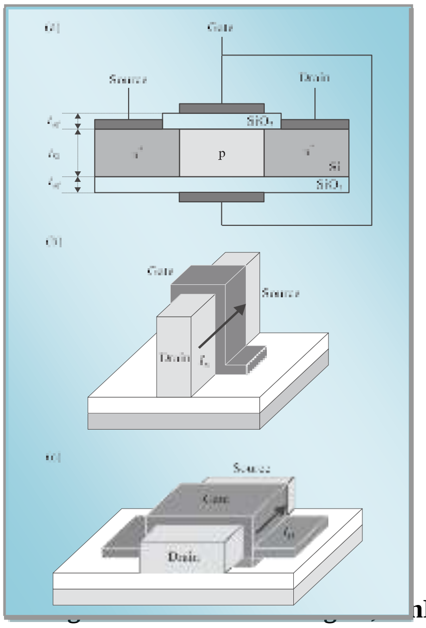

Fig. (f) nFET, surrounding gate

4.7 Semiconductor Lasers

Semiconductors are extensively used for emigration and discovery of radiation. The first report on light emitted be a semiconductor appeared in1907 in a note by H.J. Round. Fundamental work in this area was conducted among other by Losev. A veritably intriguing description of the development of light emitting diodes may be set up in (40) while the history of photovoltaic is bandied. In this section, only semiconductor spotlights are mentioned compactly.

The first semiconductor spotlights were developed around 1962 by four American exploration brigades (41). Farther exploration this area went in two directions, wider diapason of accoutrements to gain wider wavelength rang and generalities of new device structures. Herbert Kroemer and Zhores Alferov have singly come up with the idea that semiconductor spotlights should be erected on hetero-structures. Zhores Alferov was a member of the platoon that created the first soviet p-n junction transistor in 1953. He was directly involved in exploration aimed at development of specialized semiconductor bias for Russian nuclear submarines. The matter was of similar significance for the Soviet authorities that he used to admit phone calls from veritably high government officers who wanted the work done briskly. To fulfil those requests Alferov had to move to the lab and literally live there latterly he worked on power bias and came familiar with p-i-n and p-n-n structures. When the first report on semiconductor spotlights appeared, he realized that double hetero structures of the p-i-n type should be used in this bias (41). He obtained the first practical heterostructure bias and the first heterostructure ray (42). In 2000 Alferov and Kroemer entered a Nobel Prize in drugs for their achievements in the area of semiconductor heterostructures used in high speed and optoelectronics significant progress in semiconductor laser is associated among other with the use of quantum wells and new materials especially gallium nitride.

5. Summary

Silicon may be considered as the information carrier of our times. In the history of information there were two revolutions roughly 500 times piecemeal. The first was that of Johan Gutenberg who made information available to numerous, the other is the invention of the transistor presently the global quantum of information doubles every time numerous effects we are taking for granted similar as computers , internet and mobiles would not be possible without silicon microelectronics.

Electronic circuits are also present in buses home appliances ministry. Optoelectronic bias are inversely important in everyday life e.g. fiber-optical dispatches for data transfer, data storehouse CD and DVD reporters, digital cameras etc. Since the morning of semiconductor electronics, the number of transistors in an intertwined circuit has been adding exponentially with time. This trend has been first noticed by Gordon Moore (43) and is called Moore's law. This law is illustrated in fig.g where the number of transistors in consecutive Intel processors is colluded as a function of timer data after(44).

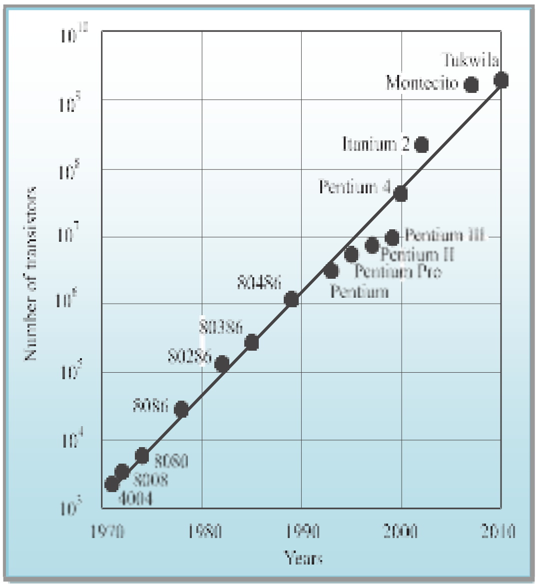

Fig. (g) Number of transistors in successive Intel processors as a function of time

Indeed though the bipolar technology was largely replaced CMOS further than 90% of integrated circuits are manufactured in CMOS technology, Moore's law is still true in numerous aspects of the development trend of silicon microelectronics obviously, with the applicable time constant. The MOS transistor has been bettered in numerous times but above every time differently it has been miniaturized beyond imagination.

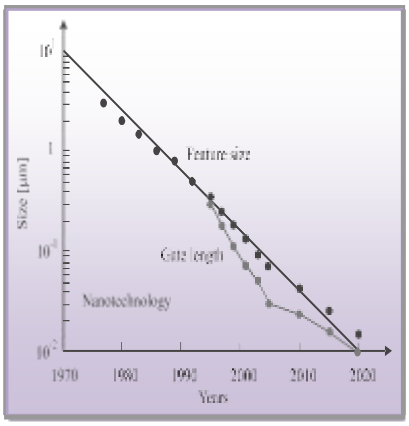

Fig.(h) Feature size as a function of time

The number of the point size presented in fig. e , is more or less exponential. The number of transistors produced per time and the average price are shown as a function of time in fig h again the change is exponential. It's being anticipated that in 2010 approximately one billion transistors will produced for every person living on the Earth.

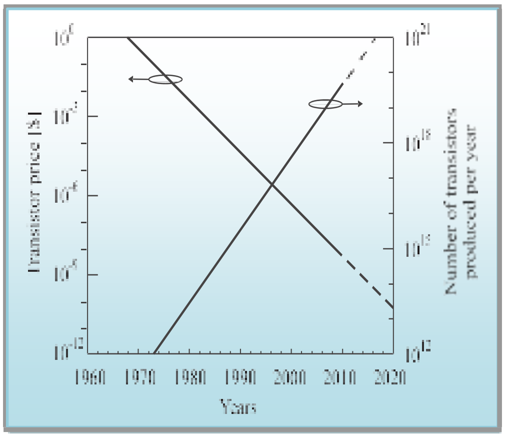

Fig. (i) Number of transistor produced per year and transistor price as a function of time

We are enough sure the future still holds a many surprises expansive exploration is being carried out on grapheme, organic electronics amount bias microsystems integration of silicon with other accoutrements and numerous other issues but that's another story.

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