Pre-1900 Semiconductor Research and Semiconductor Device Applications

Asif Islam Khan
Bangladesh University of Engineering and Technology
28/3 BUET Quarters, Dhaka-1000, Bangladesh
Email add.: shikhor_himadri@hotmail.com

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Abstract:

This paper presents a critique of the origin of semiconductors and pre 1900 developments in semiconductor research and device applications. Although the history of semiconductors stretches back to a time as far as 1833, semiconductors made debut in engineering field by dint of Bose's research in the 1890s. Selenium photoelectric cell, Braun's discovery of rectification at metal semiconductor interface and Bose's introductory applications of semiconductors for wireless engineering can be considered the milestones of the 19th century in this regard. The author puts forward a suggestion to identify Bose's pioneering research with semiconductor, which led to the development of semiconductor detectors of wireless signals and which is otherwise less pronounced, as an IEEE Milestone.

Introduction:

As it appears from most of the historical reviews of semiconductor research, semiconductor devices-preceded by the adjectives *early* and *primitive* usually, refer to the crystal rectifiers used for wireless applications in the early 1900's. In this sense, early 1900's is regarded as the time when the semiconductor devices first came into application. An investigation into the history of semiconductor research unveils even more primitive and earlier semiconductor devices- they are the semiconductor devices of the 19th century. Pearson and Brattain outlined the developments in semiconductor research before 1900 in [1]. Semiconductor research and semiconductor device application is an interest-entirely of the 20th century, in a more rigorous sense, of the second half of the century- but the roots of this discipline extend to the 19th century, too. Semiconductor properties- as fascinating as negative dynamic resistance of junctions, were observed. Use of semiconductors for wireless application began in the 1890's. The history of semiconductors in the 19th century lacks proper investigation and integration. How semiconductor properties came to scientists' notice and made debut in the field of application in the pre 1900 era presents us with an untold pre-1900 history of semiconductors.

I. History of Semiconductor Research before 1900:

The beginning of semiconductor research is marked by Faraday's 1833 report on negative temperature coefficient of resistance of silver sulfide. This is the first observation of any semiconductor property. In his 1833 paper, "Experimental Researches in Electricity" he disclosed this observation [2]. This observation was in distinction from the usual properties of metals and electrolytes in whose case resistance increase with temperature.

The next significant contributor to semiconductor field in chronological order is the French experimental physicist Edmond Becquerel. In 1839, he reported the observation of photovoltage in the silver chloride coated platinum electrodes [3]. In his experiment, a AgCl coated platinum electrode was immersed in an aqueous nitric acid electrolyte solution. Illumination of the electrode generated photovoltage that altered the EMF produced by the cell, in fact, it produced a reductive (cathodic) photocurrent at the AgCl coated electrode; this was the first reported photovoltaic device. Photovoltage was generated at the Ag/AgCl metal semiconductor contact, Ag at the junction was formed by the absorbed silver clusters in the AgCl electronic states [4] .

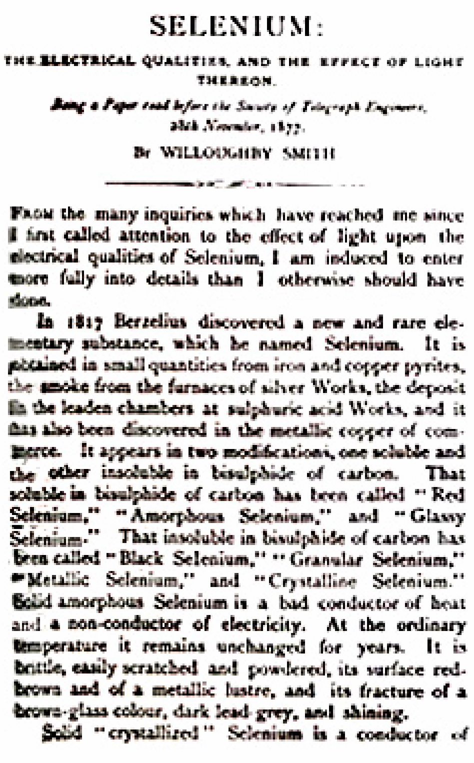
The next important decade in the semiconductor research is the decade of 1870. During this period selenium was discovered as a semiconductor, rectification at metal semiconductor interface came into scientists' notice.

In 1873, Willoughby Smith arrived at the discovery of photoconductivity of selenium [5]-[7]. How he reached at this observation has an interesting story. He was initially working with submarine cables. He set into experiments with selenium for its high resistance, which appeared suitable for his submarine telegraphy. Various experimenters measured the resistance of selenium bars, but the resistance as measured by them under different conditions did not agree at all. Then Smith discovered that the resistance actually depended on the intensity of incident light. When the selenium bars were put inside a box with the sliding cover closed, the resistance was the highest. When glasses of various colors were placed in the way of light, the resistance varied according to the amount of light passing through the glass. But when the cover was removed, the conductivity increased. He also found that the effect was not due to temperature variation.

In 1874 came the most significant discovery in semiconductor field of the 19th century- the discovery of rectification at the contact between certain materials, especially naturally occurring sulfide crystals. Braun's discovery [8] was related to natural crystals and Schuster's discovery [9] to contacts between tarnished and untarnished copper wire. In Schuster's experiment the copper oxide layer on the untarnished wire presumably acted as the semiconductor giving the contact a rectification property. Braun's experiments were more conclusive and systematic, so well approached that this is generally acknowledged as the first systematically approached study of metal semiconductor contacts.

The first observation of photovoltaic effects in a solid system was made in 1876 [10]. The semiconductor substance was again selenium. W. G. Adams, along with his student R. E. Day was investigating the photoelectric properties of selenium at Cambridge. They discovered that illuminating a junction between selenium and platinum had a photovoltaic effect.

In 1883, Charles Edger Fritts, a New York electrician, built a selenium solar cell [11]. It consisted of thin selenium wafers covered with very thin semi-transparent gold wires and a



SELENIUM:

THE ELECTRICAL QUALITIES, AND THE EFFECT OF LIGHT THEREON.

Being a Paper read before the Society of Telegraph Engineers, 28th November, 1877.

By WILLOUGHBY SMITH

FROM the many inquiries which have reached me since I first called attention to the effect of light upon the electrical qualities of Selenium, I am induced to enter more fully into details than I otherwise should have done.

In 1817 Berzelius discovered a new and rare elementary substance, which he named Selenium. It is obtained in small quantities from iron and copper pyrites, the smoke from the furnaces of silver Works, the deposit in the leaden chambers at sulphuric acid Works, and it has also been discovered in the metallic copper of commerce. It appears in two modifications, one soluble and the other insoluble in bisulphide of carbon. That soluble in bisulphide of carbon has been called "Red Selenium," "Amorphous Selenium," and "Glassy Selenium." That insoluble in bisulphide of carbon has been called "Black Selenium," "Granular Selenium," "Metallic Selenium," and "Crystalline Selenium." Solid amorphous Selenium is a bad conductor of heat and a non-conductor of electricity. At the ordinary temperature it remains unchanged for years. It is brittle, easily scratched and powdered, its surface red-brown and of a metallic lustre, and its fracture of a brown-glass colour, dark lead grey, and shining.

Solid "crystallized" Selenium is a conductor of

*EFFECT OF LIGHT ON SELENIUM DURING THE PASSAGE OF AN ELECTRIC CURRENT.**

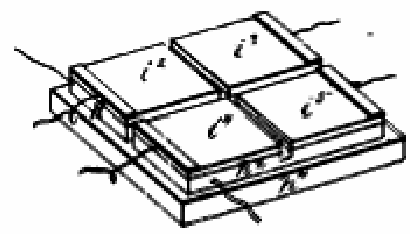
BEING desirous of obtaining a more suitable high resistance for use at the Shore Station in connection with my system of testing and signalling during the submersion of long submarine cables, I was induced to experiment with bars of selenium, a known metal of very high resistance. I obtained several bars varying in length from 5 to 10 centimetres, and of a diameter from 1 to 1½ millimetres. Each bar was hermetically sealed in a glass tube, and a platinum wire projected from each end for the purpose of connection.

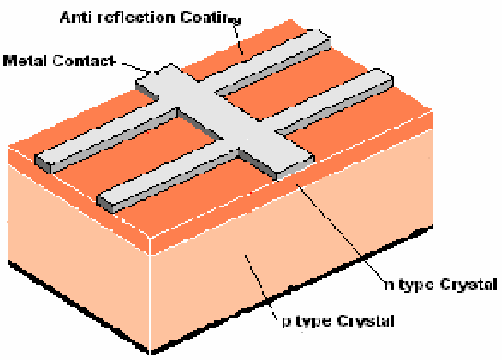
The early experiments did not place the selenium in a very favourable light for the purpose required, for although the resistance was all that could be desired—some of the bars giving 1,400 megs. absolute—yet there was a great discrepancy in the tests, and seldom did different operators obtain the same result. While investigating the cause of such great differences in the resistance of the bars, it was found that the resistance altered materially according to the intensity of light to which it was subjected. When the bars were fixed in a box with a sliding cover, so as to exclude all light, their resistance was at its highest, and remained very constant, fulfilling all the conditions necessary to my requirements; but immediately the cover of the box was removed, the conductivity increased from 15 to 100 per cent. according to the intensity of the light falling on the bar. Merely intercepting the light by passing the hand before an ordinary gas-burner placed several feet from the bar increased the resistance from 15 to 20 per cent. If the light be intercepted by rock salt or by glass of various colours, the resistance varies according to the amount of light passing through the glass.

(a) (b)

Fig 1: (a) W. Smith, Selenium: its electrical qualities and the effect of light thereon, being a paper read before the Society of Telegraph Engineers, November 28, 1877. (b) "Effect of Light on Selenium during the passage of an Electric Current", *Nature*, 20 February 1873, p.303.

protective sheet of glass. It is to be noted that, this was the first large area metal semiconductor junction device. However, it was very inefficient ($\eta<1\%$) in converting solar energy into electrical energy.





(a) (b)

Fig 2: (a) C. E. Fritts' selenium solar cell [27]. (b) Modern Solar Cell

Although the most significant observations of the 19th century came during the period 1870-1885, the semiconductors had not received any device application for any practical purpose yet. It was not until 1890's that any field recruited these materials for any practical use. Wireless communication is the first field to employ these materials for practical application.

After Hertz's demonstration of existence of electromagnetic waves in 1888, a number of scientists got involved with experimenting with this newly discovered waves, and wireless telegraphy became practicable. Among them, Bose was the first person to introduce semiconductors for the reception of wireless waves. In course of determining the various optical properties (polarization, refraction) of electromagnetic waves, he discovered that polarizing crystals had selective conductivity [12]. According to [13], this study led him to discover a galena detector, which is the first semiconductor diode detector of wireless waves. He also used point contacts of metals for detection of millimeter waves, which have I-V characteristics similar to modern semiconductor junctions [14]. Marconi's 1901 transatlantic reciever is considered the first major use of a semiconductor detector device- that semiconductor device actually originated from Bose's research in the 1890's [15].

For another time the focus shifts on Braun. In 1898, he began experiments with wireless telegraphy. He used semiconductors for reception of wireless signals, and in 1901 he realized the advantage of using them for this purpose.

Thus ends the history of semiconductor of the 19th century. The saga of semiconductor begins with Faraday's silver sulfide in 1833, and at the end of the century it enters the next century of glory with Bose's introductory application of semiconductors for wireless purposes.

II. Origin of Semiconductors, Semiconductors of 19th Century and their Properties:

When did the bizarre properties of semiconductors, different from those of both conductors and non conductors caught the attention of scientists? It was Faraday, who was the first one to discover a peculiar semiconductor property. Hence, the first semiconductor discovered is silver sulfide and the first semiconductor property is negative temperature coefficient.

Becquerel's discovery of photovoltage was a manifestation of a semiconductor property, but hardly could he imagine that he had discovered a semiconductor. In fact, his works with these semiconductor properties led to development of modern photography.

Smith's Selenium, Becquerel's silver compounds, Braun's pyrite and sulfide crystals can be considered the semiconductors of the 19th century. However, selenium happens to be the most important semiconductor of the 19th century, for its photoelectric properties attracted a number of scientists, like Smith, Adams and Day, Fritts, to do research with.

As a matter of fact, the photoelectric effects were first observed in the semiconductors(as early as 1873). The first observation of photoelectric properties in a metal came in 1887 by Hertz.

The most significant semiconductor property discovered before 1900 is rectification at metal semiconductor junctions arising from Braun's experiments. This is the first time asymmetric conduction and deviation from Ohm's law was observed. Edison effect- rectification in vacuum tube was discovered in 1884, rectification at electrode electrolyte contact was discovered sometime during the end of the century. This effect is basis of the most basic and the simplest electronic component- the diode. Sze termed 1874 as the beginning of the inception phase of the semiconductor device literature [16] and hence gave this invention utmost importance regarding device application. ["If device literature exhibits normal life-cycle characteristics (i.e. from inception to growth, to saturation, and finally to decline), we can state that the inception phase is from 1874 (the first study of metal –semiconductor contacts) to 1947 (the invention of transistor).” from [16].].

In the technical review paper [1], it has been stated that by 1885 four fundamental properties of semiconductors (i) negative temperature coefficient of resistance, (ii) rectification, (iii) photoconductivity, (iv) photo voltage had been observed. But all the properties did not occur in the same material. This is the reason behind the interesting fact that semiconductors did not appear as a different class of materials featured by a set of properties different from those of both electrical conductors and non-conductors in the 19th century. The scientist could not recognize that selenium, silver sulfide, galena, etc. actually belong to the same class of materials. They regarded them as exceptions of general laws- a more general law to differentiate between metals, semiconductors and insulators came after a long time- precisely in the 1930’s.

III. A Critique of Semiconductor Research in the 19th Century:

- Semiconductor research in the 19th century is featured by slow pace. Semiconductor research started quite unnoticed in 1833 by Faraday-more than a century before the 1947 breakthrough in semiconductor devices. The basis of electronic devices was discovered in 1874 by Braun, almost three quarters of a century before the semiconductor revolution. There was no engineering application for these materials for the most of the time during the 19th century.
- Wireless engineering was the perfect field to employ semiconductors. Transition from wired telegraphy to wireless telegraphy required semiconductors for sensitive reception of waves. It was Bose’s merit to introduce semiconductor coherers with auto recovery in place of conventional coherers in the 1890s. The basis of practical

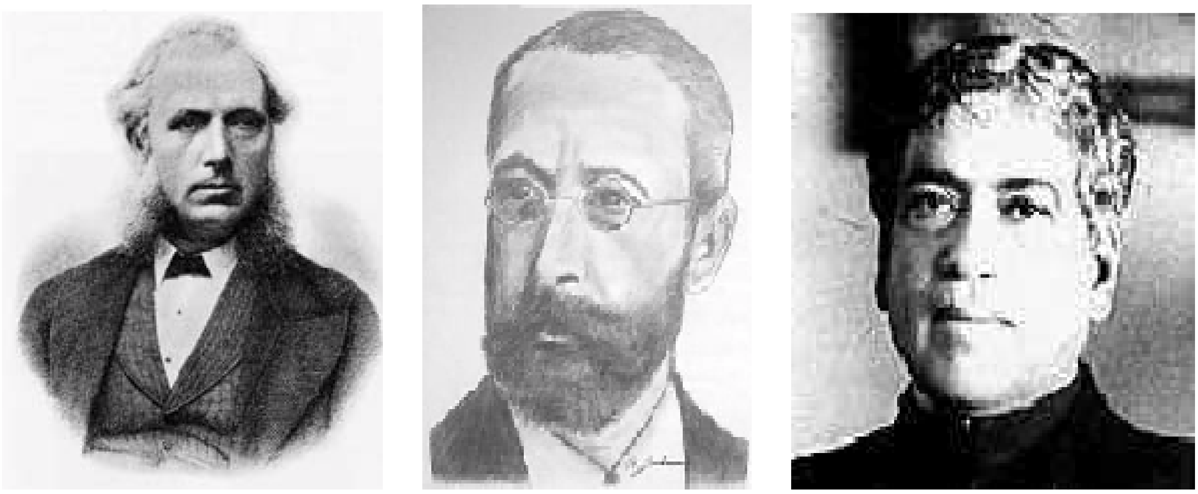
application of these materials was formed by Bose's pioneering research, which manifested in the first decade of the 20th century with Marconi's experiment.

- After 1870, semiconductor research divided into two main streams. The photoelectric properties of selenium interested a number of researchers and led the foundation of photovoltaic engineering. On the other hand, researches with semiconductor junctions led to the development of wireless detectors.
- Lack of theoretical foundation was also a reason why these materials did not find the attention of the 19th century scientists. The intriguing properties could not be explained by classical physics of the pre quantum era. For example, until 1906, a hypothesis that rectification occurred at thermal basis, existed among the semiconductor researchers. In the 1930s a complete theoretical foundation of semiconductors was established.
- It is to be noted that the scientists related to this field in that century were more famous for their works in the other field. Faraday's fame is not to be mentioned, Becquerel's discovery laid the foundation of modern photography, Braun is more famous for his oscilloscope.
- Although Bose classified some materials into p types, n types and neutral types, most of scientists could not recognize that semiconductors form a different class of materials. In 1907, it was first systematically shown by 'Hall Effect' that selenium, tellurium and silicon all were semiconductors.

Some of the outcomes of the research of the 19th century may be considered commendable achievements of the semiconductor research in the 19th century which are summarized below:

1. Foundation of photovoltaic research from the research on selenium.

2. Braun’s discovery of rectification at metal semiconductor junction making the basis of the electronics in the 20th century.
3. Bose’s application of semiconductors to wireless wave detection-first engineering application of semiconductors.



(a) (b) (c)

Fig 3: (a) W. Smith, discoverer of photoconductivity of Selenium. (b): Ferdinand Braun, discoverer of solid-state rectification. (c) Jagadish Chandra Bose, first to apply semiconductors for practical purposes.

IV. Selenium and Foundation of Photovoltaic Engineering:

Researches with photoelectric properties of selenium in the 19th century laid the foundation of photovoltaic engineering. Adams and Day’s 1876 discovery of Photovoltage at junctions is the basis of solar cells. They built the first photo element of modern barrier type [1]. The solar cell invented by Fritts’ has some features in common with modern silicon solar cells. Selenium devices began to be used widely as photographic exposure meters, rectifiers and battery chargers in the 1920’s [1]. Before the advent of silicon and germanium rectifiers, selenium happened to be one of the most important materials for the semiconductor industry. It is noteworthy that, unlike the other semiconductors of the 19th century, selenium did not lose its importance as a semiconductor; selenium and its derivatives are still used for semiconductor device applications. Endeavors in the photovoltaic field intensified after 1950.

For photovoltaic application selenium compounds, for example $CuInSe_2$ are used as principle semiconductors.

V. Braun's Efforts and Contribution to Semiconductor Research:

Braun was initially engaged in research with electrical conductivity of metal salts in solution, i.e. electrolytes. His interest ultimately led him to study metal sulfide crystals and other crystalline solids, which, although being solid binary compounds, conduct. In 1874, he disclosed his discovery of rectification effect [8]. He observed that the total resistance depended on the polarity and magnitude of the applied voltage as well as the surface conditions. From his 1874 paper, "With a large quantity of natural and artificial metallic sulfides and greatly varying pieces, the most perfectly formed crystals that I could find, as well as coarse samples, I discovered that their resistance varied with the direction, intensity and duration of the current. The differences amount up to 30% of the total amount."

Among the natural metallic sulfides and pyrites he experimented with were copper pyrite, iron pyrite, galena, and tetrahedrite (copper antimony sulfide). He observed that at small current intensity the material had a higher resistance in a certain direction, as the intensity increased the resistance diminished for both directions. However, as the intensity of current increased, at some stage the resistance in the previously high resistance direction fell below the resistance in the other direction for the same current intensity-this must be the manifestation of breakdown phenomena.

In one of his experiments, he used a shiny tetrahedrite crystal of tetrahedron shape. Two silver wires with their ends flattened were pressed hard to the crystal. One wire was perpendicularly in contact with the surface at the apex, the other was near the base line of the same surface. He found that this type of contact acted as an Ohmic contact, the current intensity was the same in both directions. When second wire was in contact with against the base of tetrahedron, the current intensity varied with the direction. This contact acted as a rectifying contact. He found the resistance of the contact was a function of the form $w + c \times J + k \times J^2$ Where, w= true resistance or reference resistance, J= current intensity, C, k= constants.

He continued his experiments until 1883 [17]. His experiments involved dc measurement of current and voltage of the crystals. His experiments and finding were confined to laboratory, as at that time he did not find any practical application of this novel effect. Braun later shifted his interest to other disciplines of physics. However, he had found this early discovery useful for wireless application not until 1901, when he used a telephone to receive the signals by hearing [18]. However, in [19] it has been showed that the wireless applications of semiconductor junction did not originate from his 1874 experiments.

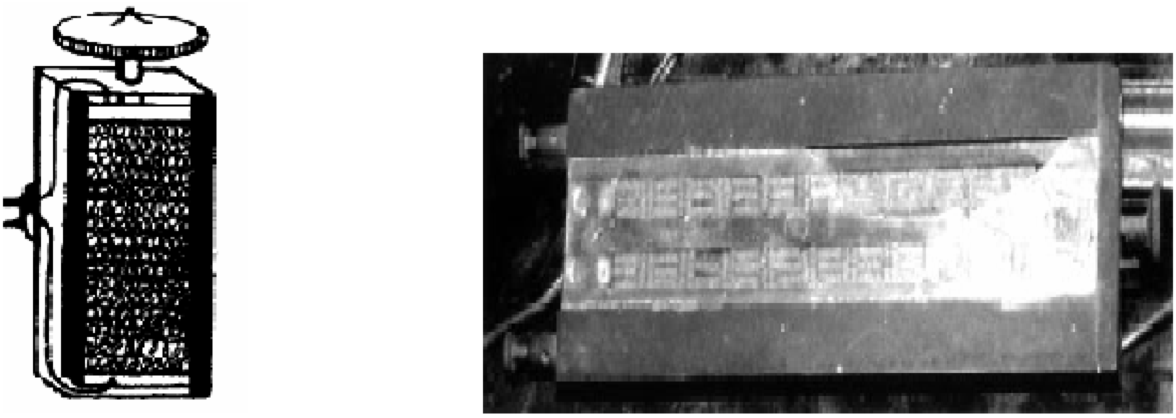
The earliest systematic study of semiconductor device is generally attributed to Braun [16]. Braun's work is so remarkable that in most of the historical reviews of semiconductor research, the history of semiconductor research begins with his 1874 discovery. The underlying principle of the most basic semiconductor device-diode is rectification at junction–which was discovered by Braun in the 19th century. The famous cat's whisker diode (point contact rectifier) came into existence from his experiments. Sze termed his 1874 paper as the first systematically approached study of metal semiconductor junction [16].

Bose-The pioneer of Semiconductor Device Application:

Introduction of semiconductor materials for the detection of electromagnetic waves is Bose's contribution. To receive the radiation, he used a variety of different metal semiconductor junctions connected to a highly sensitive galvanometer in series. He later was awarded the first patent for a semiconductor device in the world. Among his various pioneering solid-state semiconductor receivers are the spiral spring coherer, galena receiver and iron mercury iron coherer (detector) with a telephone.

Bose's Spiral Spring Coherer:

Bose disclosed the invention of this receiver in 1897 at the Royal Society. In this device, thousands of steel springs(2mm in diameter and 1cm in length) were placed side by side in a single layer in the rectangular depression of a square piece of ebonite. The springs were prevented from falling by a glass slide in the front. The contacts between the springs acted as semiconductor junctions. The fine oxide layer on the spring creates the semiconductor. This device was connected in series with a voltaic cell and a dead beat galvanometer. When electric radiation was absorbed by the sensitive contacts, there was a sudden decrease of the resistance and the galvanometer was deflected. This detector has been called Metal Semiconductor Metal (MSM) detector in [20]. This detector was described [21] as a "space irradiated multi contact semiconductor (using the natural oxide of the springs)".



(a) (b)

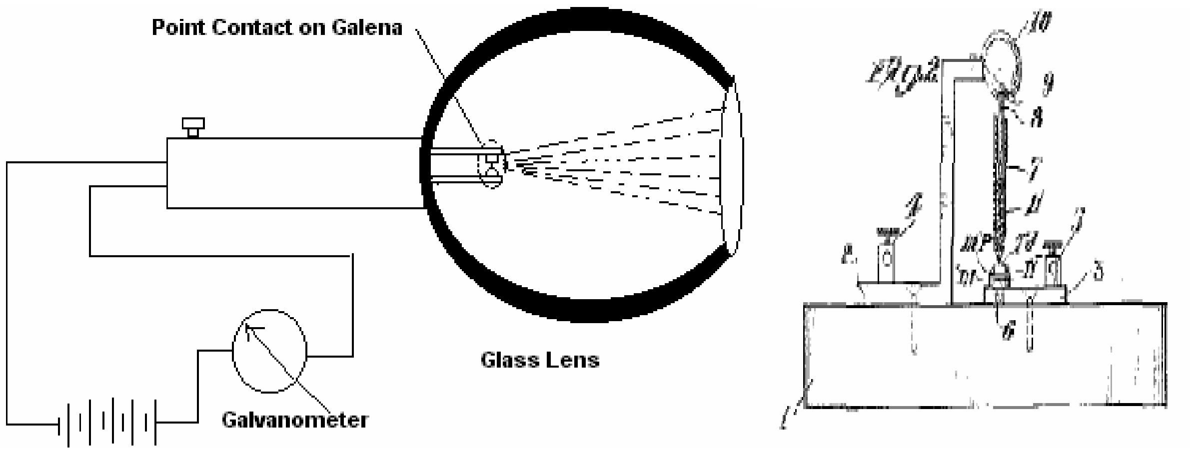
Fig 4: (a) Bose's diagram for spiral spring coherer [26]. (b) Photograph of Bose's spiral spring coherer[26].

Galena Detector- The First Semiconductor Diode Detector:

Sir J.C. Bose holds the first patent for semiconductor diode detector. It was the Galena detector [22] which he invented some time during 1894-1898 [15, 19], and demonstrated in Royal Institution Discourse in 1900 [25]. In this device, a pair of point contacts (cat whiskers), in this case of galena, was connected in series with a voltage source and a galvanometer. This device could detect any kind of radiation, 'Hertzian wave, light waves, and other radiation'. He called his galena point contact detector an artificial retina (because by suitable arrangement it could be made to detect only light wave), a universal radiometer or a tejometer (Sanskrit *tej* means radiation). According to [20] this device acted as a point contact detector for millimeter waves and as photoconducting detector for light waves and millimeter waves. He intended this device for reception of 'signals in wireless or other telegraphy'. From his patent application [22],

" A coherer or detector of electrical disturbances, Hertzian waves, light waves or other radiations, comprising contacting pieces of sensitive substances having a characteristic curve(giving the relation between an increasing electromotive force and the resultant current passing through the sensitive substance), which is not straight but is either convex or concave to the axis of electromotive force and in which the return curve with a decreasing electromotive force when taken slowly, approximately coincides with the former curve, in combination with means for adjusting the force of contact between said contacting pieces."

The main difference between Bose's detector and early 1900 detectors is that Bose's detectors worked with millimeter waves and his detector junctions were directly illuminated by the waves. Fig 5 shows the similarity between Bose's galena detector and Pickard's silicon detector (1906). Pickard's detector used a point contact on silicon which is very much similar to the galena detector. This is due to galena detector that the technical review paper [1] priority to Bose for the use of a semiconductor crystal as a detector of radio waves. In [1], it was stated that Bose's detector has the best sensitivity. The review papers, [13] and [19] show that semiconductor diode detectors or the crystal detector for wireless waves originated from Bose’s work in the pre 1900 era-it is Bose’s galena detector which is the forerunner of crystal detectors.



(a) (b)

Fig 5: (a) Bose’s Galena Detector redrawn from the original patent diagram [22]. (b):Pickard’s Silicon detector [28]. Note the similarity of Point contacts used.

Iron-Mercury-Iron Coherer with a Telephone: Receiver for Marconi’s 1901 Transatlantic Signaling:

This invention has great historical significance because of the turn-of-the-century scandal regarding Marconi’s 1901 transatlantic experiment. On April 27, 1899, Bose disclosed the invention of this device at the Royal Society meeting in London. This device consisted of a U shaped tube filled with mercury. In one limb there was a thin rod plunger, and on the other there was a sensitive material which touched mercury barely. By adjusting the position the plunger by a slide arrangement, the pressure on the contact was adjusted. The circuit was completed through the metal and mercury. The detection of micro waves was possible due to the formation of an oxide film, either on the surface of mercury or on the iron (or both). This formed a junction with rectifying property and by the sliding arrangement suitable oxidized spots were found. Thus this was semiconductor device.

In [15], Bondyopadhyay pointed out that after Bose’s disclosure of this invention in 1899, it caught the attention of a number of experimenters. Marconi carried his childhood friend and

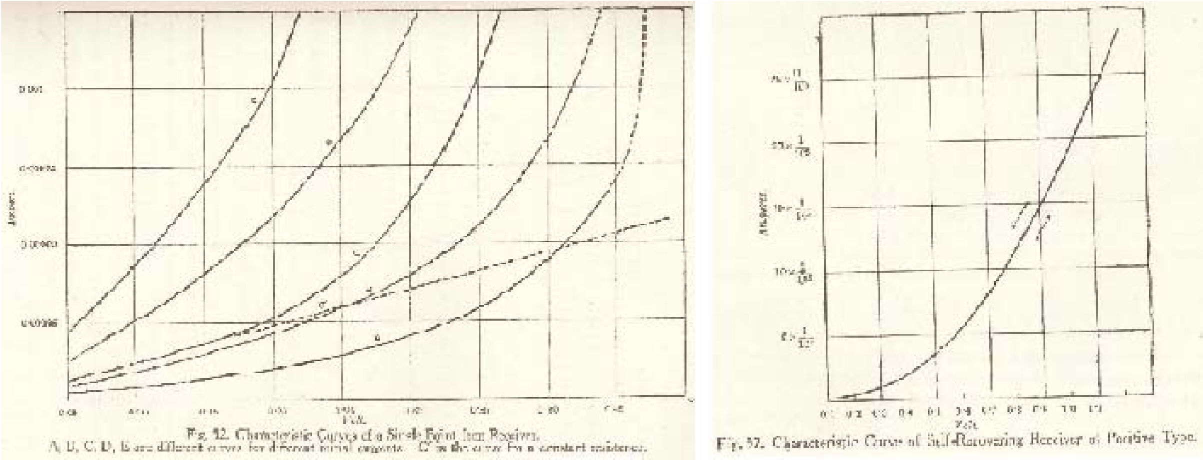
Italian Lieutenant Solari's modification of Bose's "mercury coherer with a telephone" for use in the reception of the first transatlantic wireless signal in December 1901. Scandal spurred regarding reception of the famous signal 'S' at Signal Hill in 1901 very soon. The scandal is revisited and critically analyzed in [15] and [23]. Bondyopadhyay concluded that Marconi plagiarized Bose's design, but never in his life acknowledged that. Marconi was well aware of Bose's research and even tried to hire Bose. In 1901 , prior to a Royal Institution lecture by Bose, Marconi's Wireless and Telegraphy company's managing director met Bose to with a patent application and asked him not to disclose his inventions there[29]. The price of Marconi's such conduct was that Bose's works in that field remained unknown to the world and he was deprived of the Nobel Prize, 1909. Undoubtedly, Marconi's success in the long distance wireless communication and transatlantic signaling was largely due to Bose's semiconductor Fe-Hg-Fe coherer.

Bose's Work with Junctions and Insight into Semiconductors:

Bose had some interesting observations working with point contact detectors. One of his curious receivers was the 'single point iron receiver'. It consisted of a sharp point of iron, pressing against a convex iron surface, pressure being capable of very delicate adjustment by means of a micrometer. He found that the resistance was not constant, but went through a continuous decrease with increasing applied voltage. Hence, he concluded that the conduction in such cases did not obey Ohm's law. The I-V characteristics of single point iron receiver as measured by Bose is shown in Fig 6, the different curves corresponds to different contact pressures. One of these curves is similar to the I-V characteristics of semiconductor junction having the knee approximately at 0.45V. Sarkar and Sengupta appraised this device as the forerunner of the diode in [25].

Based on the effect of electromagnetic radiation of the junctions of different materials, he divided materials into three classes, positive, negative and neutral. The positive materials show decrease in resistance under the action of radiation, the negative class shows an increase in resistance, and the neutral class do not show any change in conductivity. On the other hand, he found that junctions formed by positive or negative class materials show non linear I-V characteristics. In case of positive class the I-V curve is concave to the emf axis, and for negative class the I-V curve is convex to the emf axis, thus he correlated the radiation sensitivity and rectification effect of the point contact junctions. Be, Mg, Al, Fe, Co, Ni, Cu etc. belong to the positive class while Li, Na, K, Ca, Br, Ag belong to the negative class. The non-linear characteristic may have originated from the existence of semiconducting or insulating layer at the interface between the substances. The semiconductor junction like characteristics of positive materials may be attributed to the fact that the fine natural oxide layer (Fe_2O_3, Co_2O_3, MgO, Al_2O_3 etc.) on the metals constituted the semiconductor at the junction. On the other hand, in case of negative class materials, he observed the I-V characteristics curve convex, which is, according to [26], manifestation of negative dynamic resistance. This property, analogous to the property of tunnel diode, may be attributed to the fact that the fine natural oxide layer on the metals constituted the extremely thin insulator layer at the junction.

To appraise Bose’s work, Sir Neville Mott, Nobel Laureate in 1977 for his own contributions to solid-state electronics, remarked [26] that "J.C. Bose was at least 60 years ahead of his time" and "In fact, he had anticipated the existence of P-type and N-type semiconductors."



(a) (b)

Fig 6: (a) Characteristic curve of the Single Point Iron Receiver. A, B, C, D, E are different curves for different initial currents, C is the curve for constant resistance [14]. (b) Characteristic curve for a self recovering coherer of positive type [14].

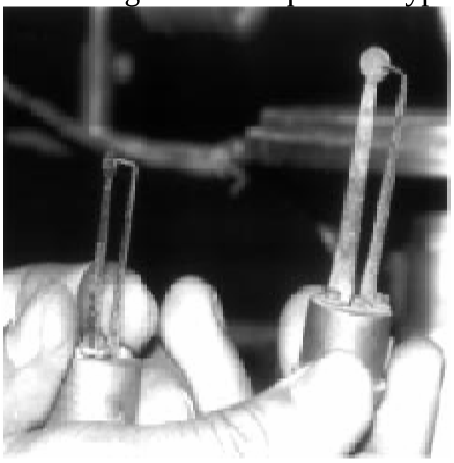


Fig. 7: Bose's point contact detector, removed from the receiving antennas [26]

Bose's Research as IEEE Milestone- A Final Remark:

Undoubtedly semiconductor engineering had its humble beginning in Bose's hands. Bose's inventions might have influenced the great innovators, like Marconi, Braun. Braun, in his Nobel Lecture[30], mentioned that, "The elements(semiconductors) showed the expected detector effect, but *at that time* offered no advantages over the coherer. As the swing to aural reception of messages took place, I came back to these materials, and recognized their usefulness for this purpose in 1901." It was Bose who introduced the idea of aural reception of signals from semiconductor detectors. Bose's global leadership in semiconductor research referred to the earliest history of semiconductor device applications is undisputed. But, the impact of his contributions to this technology is not publicized and appreciated in the modern context. Bose's research marks the beginning of semiconductor engineering. Hence the author thinks that Bose's seminal research with semiconductors deserve to be identified as an IEEE Milestone.

VI. Conclusion:

Slow pace and narrow field of application characterize the pre-1900 history of semiconductor research and semiconductor device applications. But this history surely deserves to be preserved and should be well documented. The roots of photovoltaic engineering, electronic principles and wireless applications of semiconductor devices find ground in the 19th century. No matter how insignificant the contribution of research efforts of this century is to the development of this field in the 20th century, the germ of early 1900 semiconductor device applications was there in the 19th century.

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