Evolution of Research on Electron Devices in India

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This review seeks to give a broad coverage of the research efforts in the field of electron devices in India. Starting with the earlier work in the field by Sir J.C. Bose, the pioneering effort of Prof. S.K. Mitra in initiating systematic work on electron tubes is recalled. The course of events following the advent of the semiconductor age is outlined giving brief accounts of the activities in some of the National Laboratories, research institutes, industries, the IITs and the universities. The roles of the principal funding agencies are discussed. The importance of more intensive and purposeful approach, greater interaction between industries and research organizations, better appreciation of the key role of basic investigations on development of new devices, are emphasized.

1 Introduction
The story of Professor S.K. Mitra’s tireless efforts in the thirties in introducing Radio and Wireless Communication as a subject of higher studies and research in India, is well known. Apart from the activities initiated in his own laboratory at Calcutta, he prevailed upon the Government of India to constitute a Radio Research Committee to organize a coordinated programme of work in the country. Later on, as the custodian of the Committee, he planned a concerted chain of R and D projects aimed at attainment of self-reliance in respect of vital electronic components. The most ambitious of these was the one relating to electron tubes. He carried the blueprint of the project with him while on a trip to the U.K. and the U.S.A., as a member of the Indian Scientific Delegation towards the end of 1944, located the sources of supply of important equipments, materials and literature for the project and had the same sanctioned by the CSIR early in 1945, immediately after his return. It took about a year for the equipment to arrive and the project was actually launched in April 1946. It marked the beginning of researches on electron devices as a distinct area of activities in India. The present paper seeks to cover the story of its growth since then, although, for the sake of completeness, a reference to some earlier effort in the field is certainly called for.

2 The Phases of Growth
The growth of research on electron devices in India has taken place in a number of distinct phases. These are depicted broadly in Fig.1. The pre-1946 activities may be treated as the early phase. The launching of the project referred to above, in 1946, marked the beginning of the vacuum tube phase which continues even now—undergoing changes in complexion with time. Superimposed on this, from 1960 onwards, is the phase related mostly to the transformation brought about by various technological advances in the solid state family of devices, preceded by a rather brief intermediate phase, during the 1955-60, marking an era of activities preparatory to the former. These various phases are described in the next few sections. As the activities in the earlier years (1946-65) are comparatively less known at the present time, a more complete account will be attempted for this period.

2.1 The Early Phase
Several ideas and innovations in the field of electron devices had been reported before 1946, although often in somewhat different context. The earliest recorded contributions in the field are the pioneering works of Sir J.C. Bose on microwave detectors. He had also invented a detector using a point contact galena crystal. Fig.2 is a reproduction of the original US patent certificate of the latter. A 100 years ago Bose had been thinking of a device for direct conversion of solar light into electricity. We find the following significant entry in his diary dated 5th March, 1985:

“I have been long thinking whether the vast solar energy that is wasted in the tropical region, can in any way, be utilized. Of course, trees consume the solar energy. But is there no other way of directly utilizing the radiant energy of the sun?”

Taking advantage of the heating effects, there have
been attempts to construct a solar engine which is merely a heat engine. We may also get thermoelectric current by heating one of the junctions. But such thermoelectric batteries are practically of not much use. Great amount of energy is also lost by the wasteful conduction. Now I have thinking whether we would not directly convert the energy of light into that of electric current."

And 20 years later he succeeded in developing a device that converts light into electricity and went on to have this patented along with his galena crystal detector referred to earlier. This was actually the first dry type photovoltaic cell using a compound semiconductor. However, with lapse of time Bose's interest had perhaps shifted and his patent actually dealt with the use of the device for detection and measurement of intensity of light and not for energy conversion. He called the patented device a ‘Tejometer’ a Sanskritized name for intensity meter. He also developed other quite important generating and guiding devices in course of his monumental work on microwave. Prof. Mitra gave an illuminating account of this work in his 1945 Sir J.C. Bose memorial lecture. Gaseous discharges formed topics of research at several places including Professor Mitra’s laboratory. Mitra and Sil had also done some interesting work on the transit time loading of a triode at high frequencies in 1932. The technique of fabrication of Geiger counter and Wilson cloud chamber was developed at Prof. Saha’s laboratory and the Bose Institute at Calcutta in the late thirties and early forties. Demountable vacuum tubes were successfully designed and constructed for generating high power r.f. ultrasonic waves at more than one places early in the forties. That was also the time when X-ray tubes were constructed in India. However, these were rather casual developments—incidental to work in other fields. There was no attempt at upgrading or studying them for their own sake.

2.2 The Vacuum Tube Phase

The purpose of the C.S.I.R. project of 1946, referred to earlier, was to remove this lacuna by carrying out developmental work up to the pilot plant stage. It was,
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of course, restricted in scope, to receiving tubes only. Fig. 3 illustrates some of the earliest tubes developed under the project. Laudable though, the project turned out to have been rather ill-timed because of three new developments, viz. (i) within a few months of its launching, life in Calcutta came to almost a grinding halt because of prolonged communal trouble, (ii) just after a year or so, in August 1947, India became independent, and in view of the pressing needs of defence services, the Government of India decided to go in for foreign collaboration for production of electron devices rather than adopting the more time-consuming course of development of indigenous know-how, and (iii) in another year the Bell Telephone Laboratories announced the invention of the transistor. Nevertheless, the effort continued for sometime not only at Calcutta but also subsequently at Delhi University and later on at the Indian Institute of Science, Bangalore – both on receiving tubes. The transistor had a fairly long teething trouble. This, and the momentum already generated, however, helped to carry on the work on vacuum tubes for several years more. Some of the contributions during this period included transit time effects in triode by Chatterjee and Sreekantan from the IISc, Bangalore, oxide cathode poisoning, theory and design and operation of several special types of gridded valves from the Calcutta University. A notable contribution during this phase was perhaps the investigation on thermionic emission carried out by Prof. K.S. Krishnan at Allahabad with particular reference to the method evolved by him on measurement of thermionic constants using thermal effusion.

In view of the challenges put forward by the transistor in the field of low power devices, interest at Calcutta started shifting towards high power devices and a project was framed on X-band TW magnetron. Fig. 4 illustrates a section of the laboratory built up for the purpose with the details of the magnetron developed shown in the inset. Almost simultaneously, with this, the National Physical Laboratory, New Delhi, started work in the same field with Dr Amarjit Singh as the project leader. Fig. 5 shows the components and other details of the magnetron investigated by him. The activities shifted to the CEERI, Pilani, when Singh left for the place. At Pilani he built up the vacuum tube laboratory quite quickly and did, among other things, valuable work on the development of an Inverted Interdigital Magnetron. Of the other devices investigated here, coaxial-type power tube, xenon flash lamp, TV pick-up tube, high power crossed-field devices and guns deserve mention. Meanwhile, the National Physical Laboratory, in the late fifties, launched a project on the design and fabrication of reflex klystron and carried it to the batch production stage. At a much later stage, in 1975, the Electronic Engineering Department of the BHU started a project on high power klystron and TWT. The NPL also developed know-how on CRT and TV picture tubes. None of the products developed, however, is known to have been commercially exploited. A highlight that deserves special mention was the work on thermionic cathodes and He-Ne laser at the IISc, Bangalore.

Other organizations which started work on vacuum tubes during the 60's and the 70's were: The Tata Institute of Fundamental Research (TIFR) – TR-switches and high power klystrons; The
Bhabha Atomic Research Centre (BARC) — image converters, image intensifiers and phototubes; The Bharat Electronics Ltd (BEL) — transmitting, microwave and display tubes; The Electronics Corporation of India (ECIL) — microwave and display tubes.

The above account, of course, confines to those devices which are of interest to Electronics and Communication. On a broader perspective, an electron microscope, a cyclotron and an MHD generator may be classed as special types of electron devices. Work had been carried out on development of the first two at the Saha Institute, Calcutta, and the last at the TIFR, Bombay.

2.3 The Interim Phase

Although 1948-49 saw the birth of the transistor, it took about 5 years more to have it established as a commercial proposition. This and the entirely different basic physics of its operation and the lack of availability of the relevant materials and devices in the local market constituted serious hurdles in undertaking any work with it in India. On the other hand, there were reasons to believe that it would eventually replace at least the receiving types of tubes and as such no new projects on investigation on the latter were undertaken during the period. Instead, and quite rightly, interest shifted to microwave and high power devices as already mentioned. However, some preparatory work was done to initiate researches on semiconductor devices. Transistor started appearing in the local market around 1953-54. Exploratory studies on its operation and investigations on theoretical aspects were also started, in a small way, in a few laboratories. As far as the present author is aware of, the first publication on transistors in India to appear was one on studies on transistors connected in parallel by A.N. Daw of the Calcutta University in 1955. Some theoretical works on transient response of transistors, on determination of their physical and geometrical parameters and noise, formed other contributions from the same place. The other centres to start work in the field during this period were the IIT, Kharagpur, the Banaras Hindu University, Kalyani University and the National Physical Laboratory. Work on Bose's historical point contact devices was also revived during this period at the Bose Institute. By the end of the 50's the wide ranging possibilities of the transistor in respect of gain, frequency and power had not only been clearly established but the advent of other new types of devices like the solar cell, the varactor, and the tunnel diodes had laid firm foundation of the semiconductor family of electron devices. There was little doubt that for fruitful results in the field, ad hoc approaches and casual studies would be of little help. A brief survey of activities during the interim phase has been given by Achuthan.

2.4 The Semiconductor Phase: General Features

The clear indication that semiconductor devices had come to stay helped to initiate work on them on a more planned and systematic fashion at several places in the early 60's. The most notable of these was, of course, the setting up of the Defence Solid State Physics Laboratory. The Solid State Division of the National Physical Laboratory, the semiconductor wings of the Central Electronics Engineering Research Institute and the Tata Institute of Fundamental Research also started taking shape during this period. Efforts in the same direction started in several educational
Institutions including Calcutta University, IIT Kanpur, IISc Bangalore and Jadavpur University. The well-known report of the Bhabha Committee on Electronics appeared during this decade. The crucial role of basic materials and components was adequately stressed in the report as can be seen from the estimated figures for 1965 and 1970 given in Table 1.

Although the need for adequate investment in R&D on electronic materials and devices is implicit enough in these figures, the absence of any explicit directive in this regard seems to have served as a handicap in later years. And the trend persisted even when the Electronics Commission started to function at about the end of the sixties. This was a really unfortunate state of affairs that almost swept us off our feet when, in the next decade, viz, 1970-79, the age of integrated circuits, mini- and microcomputers, MICs and Optoelectronics stormed into the world and the spectre of the energy crisis gave a tremendous boost to the researches on direct energy conversion devices like the solar cell. Some corrective steps were hurriedly initiated. The Electronics Commission set up a special Committee on Semiconductor. Valuable documents were prepared dealing with the R and D in Components and Materials and manpower training in electronics. But by then the craze for the so-called 'screw driver technology' had gathered such a momentum that the required follow-up actions almost went by default. Confusion and dithering compounded as high-tech products of this craze, marked 'Made in India' started appearing in the market, while, in reality, the electronic boom was steadily slipping out of our hands. As the age of the microprocessor established itself firmly and that of the VLSI appeared to be distinctly dawning, a move was taken once again to retrieve the lost ground through the setting up of the Semiconductor Complex and strengthening of Rand D facilities in a number of National Institutes like the CEERI, TIFR, ISRO, NPL and the creation of reasonably good teaching and research laboratories on Semiconductor Devices including ICs at the IITs and the IISc. A National task force on microelectronics was also constituted in 1982-83 to draw up a comprehensive plan of action enabling the country to leap into the VLSI age. The recommendations of the body are about 2 years old now. It is reported that an action plan, involving an investment of about Rs.500 crore, aimed at self-reliance in microelectronics, has been adopted by the Government on the basis of these. But the ball of implementation has not yet started rolling. There are reasons to fear that this might wither under the heat of the latest Government enthusiasm for imported know-how.

3 Contribution of a Few R and D Units on Semiconductor Devices

Comprehensive and planned programmes of work of semiconductor research have been, largely, lacking in India. Nevertheless, the sum total of the contributions has been quite substantial. The period 1955-65 saw, largely, the activities confined to discrete devices. New areas explored during this period included laser, infrared and submillimeter wave devices. The period 1968-70 saw some activities in the field of solar cell with Jadavpur University in the forefront. But during the next 10 years there was tremendous surge in this area at other places too.

From 1975 onwards, expansion in activities was seen on microelectronics with the IIT Delhi, the TIFR and the Semiconductor Complex dominating the scene. In the following, some representative organisation-wise break-up of activities is given. It should be stressed that this should, by no means, be regarded as complete.

(i) Industries — The BEL, the ECIL, and the CEL developed a number of devices. The BEL developed diodes, transistors, varactor diodes and TTL integrated logic circuits— maintaining close collaboration with the TIFR and the SSPL. The ECIL, maintaining similar relationship with the BARC, developed know-how for Zener diodes, power transistors, thermoelectric cooling elements and radiation detectors. The CEL developed technology for fabrication of LED and large area single crystal Si solar cells of commercial grade using imported chips. It also worked for some time on polycrystalline Si cells using the processes developed at the NPL. The BHEL at Bangalore carried out work for development of technology for making power transistors and Si-single crystal solar cells of up to 4 in in diameter.

(ii) National Laboratories — The SSPL, set up in 1962, worked on a variety of items, e.g. Si point contact diodes, Si varactor diodes, Si planar power transistors, epitaxial VHF transistors and solar cells. In this last field its contributions to the physics, design and measurement, chiefly by Jain and his associates, have been very substantial. Some linear ICs have also been successfully developed here. Lately its interest has shifted to TED, LSI and VLSI. The chief strength of

<table>
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<th>Year</th>
<th>Total production of electronic goods (in crores of Rs)</th>
<th>Value of components required (in crores of Rs)</th>
<th>Value of special materials required (in crores of Rs)</th>
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<tr>
<td>1965</td>
<td>37.5</td>
<td>6.5</td>
<td>1.0</td>
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<td>1970</td>
<td>135.0</td>
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Table 1 — Estimates of Components and Special Materials Required by the Country for Production of Electronic Goods by 1965 and 1970.
SSPL lies in the comprehensive facilities it has for studies of materials.

The CEERI at Pilani worked on the development of TO-18 and TO-5 headers, Si planar transistors, high-power high-frequency transistors, LED. Varactor diodes, thin film devices, Si logic gates including 4-input TTL-NAND and RTL-NOR and 2-input TTL-NAND gates, computer-aided circuit design facilities, solar cells using concentrated radiation and hot electron devices—the last item in collaboration with the Institute of Radio Physics and Electronics, Calcutta University. Recently it is also engaged in developing equipment for electron beam lithography.\textsuperscript{45,51–53}

The TIFR worked on Si planar devices, point contact diodes, Gunn diodes, medium and high power Si controlled rectifiers, digital ICs including VLSI/CAD, thin film hybrid circuits, \(\alpha\)-SiH devices\textsuperscript{23,24,54}.

The BARC worked on a large number of devices including special types of devices like pulsed and Raman lasers and Gunn diodes\textsuperscript{24,55–59}.

The NPL had worked on thin film and rectifier type devices\textsuperscript{59–61}. It developed considerable facilities for making polycrystalline Si and thin film \(\text{Cu}_2\text{S-CdS}\) solar cells\textsuperscript{44}. Of late, it has also developed substantial facilities for growing and studying of amorphous Si (Ref.59). A somewhat related achievement was the development of know-how for xerography.\textsuperscript{51}

The NCL had, early in the sixties, done some work on design of solar cells.

The Vikram Sarabhai Space Centre at Trivandrum had for some time worked on development of thin film \(\text{Cu}_2\text{S-CdS}\) solar cells\textsuperscript{43}. The Bombay IIT has received adequate funds to receive the support it deserved. Nevertheless, its contributions to the understanding and operation of the transistors, the Gunn diodes, hot-electron physics, the IMPATTs, the \textsc{UJT} junction-type lasers, Schottky-barrier diodes and the solar cells have been quite substantial over the years\textsuperscript{92–93}. It is encouraging to note that, very recently, it has received adequate funds for strengthening facilities for crystal growth, and fabrication of microwave and microelectronic devices.

As already mentioned the Institute of Radio Physics and Electronics of the Calcutta University has been the pioneer in the field of researches on semiconductor devices. Unfortunately, the lopsided and faulty national policy of excluding the universities from the main stream of research efforts, did not allow it to receive the support it deserved. Nevertheless, its contributions to the understanding and operation of the transistors, the Gunn diodes, hot-electron physics, the IMPATTs, the \textsc{UJT} junction-type lasers, Schottky-barrier diodes and the solar cells have been quite substantial over the years.\textsuperscript{82–93} It is encouraging to note that, very recently, it has received adequate funds for strengthening facilities for crystal growth, and fabrication of microwave and microelectronic devices. At the Banaras Hindu University its Physics and the Electronic Engineering Departments have been quite active in semiconductor device researches. The main item of investigation has been the solar cell. Recently, the laboratory has been modernized and work on the IMPATT and Optoelectronic devices has been initiated\textsuperscript{43,44,94–98}.

Jadavpur University had been engaged in a large number of devices including special types of devices like pulsed and Raman lasers, infrared and sub-mm wave detectors and modulators in the sixties (Ref.6). It had been the pioneer in India in researches on solar cells with emphasis both on the physics and on the design and fabrication of thin film solar cells\textsuperscript{38,99–113} and development of X-ray xerography\textsuperscript{114,115}. 

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The Poona University started systematic work on \( x \)-SiH solar cells a couple of years back.

Among other works worth mentioning are on FET bipolar junctions at the Gorakhpur University etc., on IR detectors at the SV University, Tirupati, on CdSe solar cells at Indore University, on GaAs solar cells at Indore University, on GaAs solar cells at Indore University, on GaAs solar cells at Indore University, on GaAs solar cells at Indore University, on GaAs solar cells at Indore University, on GaAs solar cells at Indore University, on GaAs solar cells at Indore University.

4 Concluding Remarks

It would appear from the above that the volume of activities on electron devices in India has certainly grown considerably over the years. But a coherent evolution in the field has not taken place. This has been caused, largely, by the absence of a clear-cut National Policy on this matter. The setting up of the Semiconductor Complex and the formation of the national task force on microelectronics and its comprehensive recommendations aimed at catching up with the age of the VLSI had given much room for hope. The move for creation of national Si facilities, and of a National Microelectronics Council, and the start of a policy of providing liberal support for building up research centres at the academic institutions, are also healthy signs in this respect. But as yet the primary need of a research-conscious, innovation-minded and forward-looking electronics industry and its continuous interaction with the National Laboratories and academic research centres, remains a distant goal. All efforts would prove to be futile unless this is realized. And for this a firm policy of basic self-reliance in electronics industry must be clearly announced and vigorously pursued. It is all the more necessary in view of the latest policy of liberalization of import of know-hows. This latter must not be adopted, as an ad hoc measure, to achieve a short-term, apparently rosy goal. Rather, a plan of action must be carefully chalked out for assimilation of these as a means of toning up a natural growth of indigenous effort ensuring a true evolution of our researches in the field of electronic materials and devices.

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