

BISWARANJAN NAG

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B. R. Nag



BISWARANJAN NAG

(1932-2004)

Elected Fellow 1978

The Institute of Radio Physics and Electronics, the first University department in India to conduct postgraduate teaching programme in Electronics, Communication, Computers and Radio Science, was established by Professor Sisir Kumar Mitra, FRS, in 1949. Under his stewardship and the able management of his student Professor Jatindra Nath Bhar, the Institute earned the status of Centre of Advanced Study from the UGC. If these two illuminaries laid the foundation stone, it was Professor Biswaranjan Nag, who is the main architect for earning the international recognition for the Institute. Biswaranjan did research in many areas; however for his pioneering work in semiconductors, he may rightly be called the "father-like figure in semiconductor research in India".

BIRTH, PARENTAGE AND CHILDHOOD

Professor Nag was born in Comilla (now in Bangladesh) in his maternal uncle's house on October 1, 1932. Biswaranjan was the third son of Satyaranjan and Sailabala. His father was an advocate of high repute in Pirozpur, a town in the district of Barisal in the undivided province of Bengal during the British raj. The well-to-do family was respected by the local community for its high standard of education, uprightness and patriotism. The pious family had deep faith in the preaching of Rama Krishna Paramhansa and Swami Vivekananda, which left a deep and ever-lasting impression on the mind of the child Biswaranjan. Barisal gave birth to many educationists, patriots, armed revolutionaries, as well as freedom fighters following the Gandhian path. Life was plain and simple at that time, all communities lived in peace and harmony, morality was deeply respected and practiced by the society, yet all the people impatiently wait for independence. Child Biswaranjan grew up in this socio-political atmosphere.

EDUCATION

Biswaranjan had his early education at Pirozpur Government High School. From his early days, he developed the special aptitude for arithmetic and then Mathematics. In some of his autobiographical sketches Biswaranjan mentioned that he was among the first top five students in lower classes. However, in higher classes he secured the topmost position. Unfortunately his final matriculation examination took place at the time of partition of India. His result in Matriculation was not too satisfactory in the sense that he could not secure one of the top ten positions in the University.



family faced the real crisis around that period in East Pakistan and decided to move. Biswaranjan left for Calcutta alone with a meagre amount of Rs. 50/= in his pocket. He got admission in Belur Ramkrishna Mission Vidyamandir to study I.Sc. with a free studentship. Yet he had to struggle hard to earn money for his livelihood by offering private tuition. At that time an exercise book cost four paise at Belur but three paise at Howrah. In order to save one paise Biswaranjan frequently walked the long stretch of a few kilometers between Belur and Howrah. Again his rank in I.Sc. examination was not very satisfactory; he stood 16th in the University. He then joined Presidency College of the University of Calcutta to study B.Sc. with Honours in Physics and stood second in first class. At the postgraduate level his choice was M.Sc.(Tech) in Radio Physics and Electronics. The Institute of Radio Physics and Electronics (INRAPHEL) offered the course since its inception in 1949. Infant though the department was at that time, the Institute was rapidly gaining importance in the post independence era, thanks to the vision and influence of Professor Sisir Kumar Mitra and to the dynamic leadership of Professor JN Bhar. Biswaranjan studied under a galaxy of talented and motivated teachers and their training left an everlasting impression in his future life and career. He completed M.Sc. (Tech) with highest position. The deep faith and devotion to the preaching of Ram Krishna Paramhansa and Swami Vivekananda by his family and father, inculcated in him in his boyhood, and his association with Swamijis in RK Mission also shaped his lifestyle and character.

SCIENTIFIC RESEARCH

Biswaranjan worked for a year and a half at ISI, Kolkata. In 1956 INRAPHEL was having a vacancy and Professor Sisir Kumar Mitra, the great visionary, was on the lookout for a bright student. Professor JN Bhar and Dr. Arun Chowdhury suggested the name of Biswaranjan. Professor Mitra summoned Biswaranjan and instructed him to join INRAPHEL as a Lecturer almost on the next day! The achievements of Professor Nag and his contributions to the University and the country clearly indicate how far-sighted Professor Mitra was.

After joining the department Biswaranjan initially worked on non-linear oscillators and circuits and computers. He made a significant contribution to the fabrication of the first Analog Computer in India under the supervision of his teacher Dr. Arun Kumar Chowdhury. Unfortunately however a personality clash occurred between Chowdhury and Nag and the latter completed his Ph.D. work almost independently. Biswaranjan however always praised with open heart the good training he received from Professor Chowdhury and the mastery of his teacher in electronic circuits and computers. After completing his thesis he went to the University of Wisconsin, USA, under a TCM programme with a scholarship. He made the most of his long stay by joining the MS programme there. He earned the



MS degree with A grades in all the courses working on Parametric Processes for his thesis. His one-year stay in the USA changed his research life radically.

Back home, Biswaranjan started work on hot electron transport in n-type Ge. His group was the first to report the anisotropic behaviour of hot-electron Hall mobility and magnetoresistance under high field. The high voltage pulser, the magnetometer using nuclear magnetic resonance, magnet power supply: all were built by him and his students. The Ge ingots came as a gift and cutting a slice, shaping it into the form of a dumb-bell with an ultrasonic cutter and contacting techniques were also developed. He and his students worked almost 12-14 hours in all the seven days in the week. The real challenge came in interpreting the results. The available theory was the deformation potential scattering of electrons and phonons by Schockley and Bardeen. The workers were slowly realizing the importance of optical phonon scattering. Biswaranjan and his students searched the library of the adjoining Saha Institute of Nuclear Physics, copied the papers with pen and paper, developed a working knowledge of Quantum Mechanics and perturbation theory and finally gave an interpretation. From then, it was mandatory for the next groups of researchers to learn Quantum Mechanics and Electron-Phonon interaction. In addition, students were urged to learn computer programming and run their programmes in IIT- Kharagpur and ISI-Kolkata.

The hot electron studies were repeated then for n-type Si: the most important semiconducting material. His group reported the anisotropic nature of high field conductivity, Hall mobility and magnetoresistance in n-Si for the first time. However, more importantly the study led to the complete understanding of the scattering mechanism in n-type Si, in particular the dominant role of one type of intervalley scattering proposed by D Long. An Italian group challenged the conclusion of Nag's group. Subsequent theoretical work on conductivity, piezoresistance and free carrier absorption by Nag's group and detailed experiment conducted at Bell Labs resolved the controversy in favour of the Long model.

Biswaranjan and his workers also worked on microwave properties of artificial dielectrics. A contactless microwave technique to measure the lifetime of carriers in semiconductors, proposed and demonstrated in his laboratory was widely used by workers elsewhere and is still cited today.

His group also started work on the microwave oscillators using the then discovered Gunn diodes and reported the first such oscillator made in India. The tiny diodes were fabricated in the lab. by separating a piece, as small as or even smaller than a grain of salt, with a sharp razor blade from a piece of n-type GaAs wafer, and then contacting and bonding the grain to suitable mounts. The nanosecond pulsers were also built in-house. Some work on logic circuits using Gunn diodes was also performed and reported.



Based on his exhaustive research, both theoretical and experimental, Biswaranjan then started writing a book on Theory of Electrical Transport in Semiconductors, which was eventually published by Pergamon Press, Oxford. The final manuscript was submitted during his visit to University of North Wales, Bangor. In his one year stay in UK, Biswaranjan started work on two aspects of electron transport theory: Monte Carlo particle simulation and an iterative technique to solve Boltzmann equation in the presence of non-randomizing collision, e.g., polar-optic phonon scattering in compound semiconductors and alloys. He made exhaustive work on hot carrier noise in semiconductors by using Monte Carlo technique and made some important contribution in the topic. He also developed the expressions for matrix element of electron-phonon and electron-impurity interactions for non-parabolic energy bands. The Bloch envelope function of electrons is refined by using an 8 band k.P Hamiltonian. Biswaranjan derived the overlap integral for electron scattering under such sophistication of band structure. He consolidated all his research in his second monogram Transport in Compound Semiconductors published by Springer-Verlag, Berlin in 1980.

An important change in the field of semiconductors occurred slowly in the early seventies, with the development of Quantum Nanostructures. Biswaranjan entered into the subject at its infancy. His calculation of miniband structure in semiconductor superlattice published in 1975 immediately caught attention of workers. This work is still considered and cited today as a seminal work. From this time onwards, Biswaranjan concentrated on the study of transport and optical processes in these structures, particularly on Quantum Wells, Wires and Dots made of III-V and II-VI compounds.

Another significant contribution by Biswaranjan along with his student and colleague is to formulate for the first time the alloy scattering limited mobility of two-dimensional electron gas and demonstration of its temperature independence. Nag also contributed profusely to the study of electron-phonon interaction and other scattering processes in low dimensional semiconductor structures. He demonstrated the non-parabolic nature of energy dispersion relation for electrons for narrow Quantum Wells. He also refined the theory of interface roughness scattering limited mobility for Quantum Wells with finite barrier height and well width, in which the wave functions penetrate significantly into the barrier. He also developed empirical relation for the permittivity in a few alloy semiconductors. He devoted all his research effort to the study of electron transport and optical processes in Quantum Nanostructures till the last day of his life. Based on his research in this area he authored his third book entitled Physics of Quantum Well Devices, which was published by Kluwer. A few months before his demise he presented a correct value of band offset in a few nitride based heterojunctions that created sensation and he was invited to present his findings in a few international conferences abroad.



Biswaranjan is one amongst the few scientists who felt at ease in both theory and experiment. Apart from his work on hot electron effects and Gunn oscillators, he and his coworkers worked on growth and characterisation of a few III-V compounds and heterostructures by Liquid Phase Epitaxy.

In addition, Biswaranjan took active part in the study of ionospheric physics by using the instruments developed in his laboratory as well as the recorders and other instruments located at Haringhata Field Station of the Institute.

PROFESSIONAL CAREER

(A) *Teacher*

At the time of Biswaranjan's joining the Institute as a Lecturer, the subject of Electronics was growing at a rapid pace. Books and learning materials were not available in plenty. Being the youngest faculty, Biswaranjan was assigned teaching of unpopular subjects. His indomitable spirit however overcame all the impediments and he soon earned the name of a good teacher. He had the experience of being the teacher of his erstwhile classmates. Once asked how he felt in their presence, he answered that he never felt that he was a Teacher (the usual grim faced man whom the students either fear or heckle in the class). In the next ten years his reputation as a teacher rose to still higher heights. However, all his students preferred to keep a distance from him due to his personality and academic achievements. Even his early Ph.D. students who were hardly 5-6 years junior to him were always at their toes and were afraid of being reprimanded for any lapses. Perhaps hard work and his inherent restlessness to achieve his target in time made him behave slightly rudely. A few hours later however, he became repentant and made all efforts to appease his students. In his later years the situation changed completely!

Biswaranjan was promoted to the post of Reader in 1964. He applied for a Professorship a few years later, but his senior colleague was given the post. However the members of the selection committee were so impressed by his bio-data and achievements that they strongly recommended to the University to create a post of Professor by applying to the UGC. The post was sanctioned and Biswaranjan was elevated to Professorship in 1968. In 1990 the syndicate of the University decided to create a Chair in the name of Professor SK Mitra after his birth centenary and Biswaranjan became the SK Mitra Professor.

It is difficult to compare the levels of success of Biswaranjan as a teacher and as a researcher. He could explain difficult matters in very lucid way, avoiding mathematics. His training in practical classes with his mastery in electronic circuits was adequate to raise a technologist.



(B) Academic and Scientific Administration

Biswaranjan served as the Head of the Department of Radio Physics and Electronics during 1980-82, and the Department of Electronic Science during 1988-91. He was named by the UGC as the Programme Coordinator of the Centre of Advanced Study in Radio Physics and Electronics, a post he held till 1992. He also served as the Dean of Faculty of Engineering & Technology, University of Calcutta for four years.

Biswaranjan developed close ties with a few Universities in UK through his visits. This resulted in bilateral exchange programme between INRAPHEL and these Universities with support from UGC and British Council. A few distinguished young researchers visited INRAPHEL under this programme and initiated new research activities in the Institute, by which younger faculties were immensely benefited. One such activity was the study on Gunn oscillators. The research attracted the attention of the Defence Research & Development Organization and with its support a Centre for Research and Training in Microwaves was established at INRAPHEL. The Institute could procure a number of sophisticated equipments under the support from British Council and DRDO. A few years later he initiated research on epitaxial layers of III-V compounds. The equipment for Liquid Phase Epitaxy, hydrogen purifier and the like came as gift from UK through the collaborative programme. The work in this area was further supported by DoE and other Government organizations.

Apart from these activities, Biswaranjan took active part in developing the centralised Library in the Science College campus as well as the Calcutta University Computer Centre for which financial support came from the UGC.

As a member of the UGC Committee, Professor Nag made several important recommendations about the spread of education in Electronics in India. The emergence of departments of Electronic Science in several Universities is the outcome of such recommendations. In the University of Calcutta, the stream of Electronic Science was initially attached to the Physics department. When the University decided to create a separate department, Professor Nag was given the responsibility to serve as the first Head of the department of Electronic Science during 1988-91.

AWARDS AND HONOURS

Professor Nag received the Premchand Roychand Scholarship and Mouatt medal of the University of Calcutta for his thesis on non-linear oscillators. He received the Fulbright scholarship to visit USA. He was also awarded in 1962 the J. C. Bose award by the British Institute of Radio Engineers (renamed as Institution of Electronic & Telecommunication Engineers) for his paper on Non-ohmic Transport in



Semiconductors. He earned the D.Sc. degree of the University of Calcutta in 1970 for his thesis on Hot Carrier Transport in n-type Ge. In 1973 Professor Nag was selected for the Jawaharlal Nehru Fellowship. The coveted Shanti Swarup Bhatnagar Prize for Physical Sciences for 1975 was conferred on him. He also received the INSA Materials Science Prize from the Indian National Science Academy in 1992. In 1990 he decorated the Chair of the SK Mitra Professor, newly instituted by the University of Calcutta. After his retirement from service University of Calcutta conferred on him the title of Eminent Teacher of the University in 2000. He was awarded the S. K. Mitra Centenary award by the Indian Science Congress Association in the Indian National Science Congress held in Delhi in 2002.

Professor Nag was elected a Fellow (FNA) of the Indian National Science Academy (INSA) in 1978. Later, he became a Fellow (FASc) of the Indian Academy of Sciences, Bangalore. He was a Founder-Fellow (FNAE) of the Indian National Academy of Engineering.

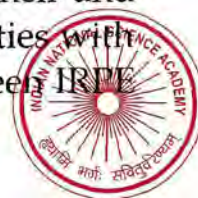
He was a member in the councils of many organisations like Indian Association for the Cultivation of Science, Saha Institute of Nuclear Physics, Indian Statistical Institute, and Indian National Academy of Engineering. He was in the senate of IIT, Kharagpur. He served in the boards of Semiconductor Complex Ltd. (Chandigarh), West Bengal Electronics Industries Development Corporation, WEBEL Crystals Ltd, WEBEL Electro-ceramics Ltd, and WEBEL Video Devices Ltd., WEBEL Television Ltd. He served as President of Bhagabati Debi Balika Vidyalaya, Salt Lake, Kolkata. He worked as experts in various CSIR, DoE and UGC committees and in selection committees of IITs and different Universities.

An international Workshop entitled Nanostructures, Applications & Goals (NAG) was organised by his Institute in 1998 to honour him after his retirement from the University service. The Workshop was followed by an International Conference Computers and Devices for Communication (CODEC) organized to celebrate the golden jubilee of the Institute, as well as to honour him.

Professor Nag was a Senior Member of IEEE for a few years. He served in the Editorial Board of Solid State Electronics (Pergamon Press), Transactions on Microwave Theory & Technique of the IEEE (MTT) and a few national journals of repute for many years. He was a regular referee of the Applied Physics Letters and Journal of Applied Physics, published by the American Institute of Physics.

FOREIGN VISITS, NATIONAL REPRESENTATION

Biswaranjan had his first foreign visit in 1959-60 to USA as a TCM participant. He made the most of his stay by studying MS in the University of Wisconsin. He visited a few Universities in UK in 1966-67 under the support from British Council and during his six-month's stay he developed research collaboration and strong ties with University of Sheffield and London. A bilateral exchange programme between IIT



and a few UK Universities soon emerged and under its auspices a few bright and young faculties came to INRAPHEL. He spent the year 1971-72 in University of North Wales, Bangor, as a Commonwealth Visiting Professor. He represented India in 1975 in the URSI General Assembly meeting held in Lima, Peru. He presented a paper in the Hot Electron Conference held in Denton, USA in 1977 and then visited IBM Research Lab and several other places in the USA and UK. His visit in UK led to a collaborative research programme and bilateral exchange of faculties between UK Universities and INRAPHEL. He was a member of the Indian team to attend the Indo-USSR Conference on Materials held at Novosibirsk, USSR in 1984. In the same year he was in the team of Indian experts visiting Japan to explore collaborative research programmes between the two countries. He presented a paper in the Hot Electron Conference held in Innsbruck, Austria in 1985. He was in Aachen, Germany in 1990 to present his paper in the SPIE Conference. In November 2003, just a few months before his demise, he delivered an invited talk on his latest findings about Nitride based semiconductors at an International Conference held at Marquette University, Australia. As his research created an impact, he received an invitation from the Organizers of an International Conference in France. However, the visit could not unfortunately take place due to untimely termination of his life.

FAMILY

Biswaranjan was married to Mridula in June 5, 1964. His wife was a brilliant student in English and worked as a Lecturer in South Calcutta Girls College, an undergraduate College under the University of Calcutta. Their son Biswadeep was born in 1969. Biswadeep too had a bright academic record. After obtaining B.E. in Computer Engineering from Jadavpur University he did M. Tech in IISc, Bangalore and then completed Ph.D. from University of Wisconsin-Madison. He is employed by Sun Microsystems. He is married with a son and his family is staying in the USA. Mriduchanda, the daughter of Biswaranjan and Mridula, was born in 1974. She also completed B. Arch from Jadavpur University and M. Arch from Delhi. She is married and the couple is employed in a firm at Mumbai.

Biswaranjan built his own house at Salt Lake, Calcutta and his family led a plain and simple life, but always striving for academic excellence and high values. Biswaranjan was devoted to his family. Mridula was a jubilant lady; but felt ill quite often in her middle age. Biswaranjan looked after the children and all household activities during her illness and hospitalization, but never absented himself from his Institute and work. Mridula was seriously indisposed in the last two years of her life. In the absence of their son and daughter her husband was her only companion. Biswaranjan cut a fine balance between his duties as husband and as a researcher. Mridula breathed her last about two years earlier than Biswaranjan.



LAST DAYS

Biswaranjan led a lonely life in his house for about two years. Yet his indomitable spirit engaged him in academic activities even in his last day. He was busy in writing another book highlighting the recent developments in the theory of electron transport. Unfortunately however an unpleasant incident in the Science College campus totally disheartened him. To aggravate matters a high value of triglyceride content in his blood was detected. He was under medication and started the usual morning walk. He even stopped coming to his Institute. All his students repeatedly requested him to spend at least some time in his office to overcome his loneliness. He however expressed his inability and of bad health. He served as the Chairman of the International Conference on Centenary of JC Bose's patent on Detectors during March 29-31, 2004. His admirers present there could notice the sign of fatigue and illness in his face.

On his last day, when he was taking tea after morning walk, he complained to his attendant of severe chest pain. He was rushed to a nearby nursing home, where the medicine was injected immediately to dilute a blood clot in artery. Total blockage of arteries was detected; however his condition was too serious and transfer to a better nursing home was ruled out. He could see his daughter, who managed to fly from Mumbai. Defying all the attempts of the attending physicians, he breathed his last at 5.12 AM on next day, April 6, 2004.

EXTRA CURRICULAR ACTIVITIES

Biswaranjan was a real workaholic. Most of his time was spent in teaching, research, academic administration and as advisors to various academic institutions and industrial organizations. In spite of all, he gave constant company to his family members and made regular holiday trips to places of interest in India. In his late thirties he used to play badminton with his colleagues, his own and other research scholars during the winter. In his own institute he squeezed some time everyday to have friendly chats with his students and colleagues. The topics of gossip covered a wide range: politics as usual, cinema including popular Bollywood films, sensational news items, literature, history of science, science in India, and above all philosophy, religion and occultism. He had faith in astrology, could prepare horoscopes and predict on its basis. His deep faith in teachings of Ramakrishna and Vivekananda and his knowledge of Veda, Upanishad and Gita, placed him in the command role in all such discussions. However, he encouraged his younger students and colleagues to become the lead speakers in areas he considered himself less familiar and authoritative. As usual all such chitchats ultimately led to debates and altercations. His colleagues, all his erstwhile students and Ph.D. scholars, had the cheek to challenge him in many such discussions. However, these debates never affected their personal relationship. All his students were extremely proud to be his disciples.



Professor Nag formed the Radio Physics and Electronics Association: a body of the alumnus of INRAPHEL and became the first Secretary in 1960. He served as Chairman of the Association many times and contributed popular articles in Bengali to the annual souvenir of the Association.

Professor Nag also wrote a number of popular scientific articles in Bengali for the periodical Jnan-Bignan: a brainchild of Professor Satyendra Nath Bose. He also wrote and published three books in Bengali on different aspects of Physics. His long association with RK Mission prompted him to contribute scientific and philosophical articles to the Missions periodical Udbodhan. He delivered lectures at the Mission's Institute of Culture and was involved in various academic activities of the Institute.

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The authors are grateful to the son, daughter and other family members of late Professor Nag for providing useful information about his personal life. Many students and friends of Professor Nag directly or indirectly contributed to the preparation of this memoir. The authors acknowledge their help, but do not make a list lest somebody should be left out.

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LIST OF PH.D. STUDENTS

Professor Nag supervised directly about 23 Ph.D. candidates. The names of these students, year of Ph.D. award, the title of their thesis, and the place where they spent most of their professional life are given in the following list.

1. Pankaj Das (1964) Studies on hot carrier Hall mobility and microwave conductivity of semiconductors (Renssalaer Polytechnic Institute, Troy, New York, USA).



2. Hrishikesh Paria (1966) On the hot carrier galvanomagnetic properties of n-type germanium (Ex-Head and Professor, INRAPHEL, CU).
3. Meher Hostang Engineer (1966) On some aspects of microwave propagation in semiconductors and artificial dielectrics (ex-Director [actg] and Professor in Physics, Bose Institute, Kolkata).
4. Dipendra Nath Basu Mallick (1967) Some studies on grounded grid oscillators for cyclic particle accelerators and on some associated oscillators (deceased : SINP and VECC).
5. Subhendu Guha (1967) On some aspects of hot electron galvanomagnetic and microwave transport in germanium (Senior Vice President, United Solar, Troy, MI, USA).
6. Amar Nath Datta (1969) On some aspects of Faraday rotation in semiconductors, artificial dielectrics and ionised media (Professor, INRAPHEL, CU).
7. Samir Kumar Lahiri (1970) Current instability in cadmium sulphide platelets (Deputy Director of, and Professor in E&ECE Department, IIT - Kharagpur).
8. Prasanta Kumar Basu (1971) Studies on the high field conductivity, Hall mobility and magnetoresistance of n-type silicon at 300 K (ex-Head and Professor, INRAPHEL, CU).
9. Debashish Chattopadhyay (1972) Some aspects of hot carrier transport in semiconductors (ex-Head and Professor, INRAPHEL, CU).
10. Debidas Mukhopadhyay (1973) Studies on electrical conduction and Faraday rotation in semiconductors (ex Head and Professor, E&TCE Department, Jadavpur University, Kolkata).
11. Anjan Kumar Das (1979) Free carrier infrared absorption and electron scattering in some n-type compound semiconductors (in Government service).
12. Gour Mohan Datta (1980) Electrical transport in compound semiconductors (Reader, Shyampur Siddheswari College, under CU).
13. Deb Mukherji (1980) Energy levels and electron statistics in superlattices and related heterostructures (Department of Physics, University of Patna).
14. Phatik Chandra Rakshit (1980) Studies on Gunn oscillators (Head and Professor, INRAPHEL, CU).
15. Chanchal Kishore Chattopadhyay (1982) Studies on microwave properties of semiconductors and semiconductor microwave circuits (DEAL, Dehradun).



16. Sunanda Dhar (1981) Some experimental techniques in the study of semiconductors (ex Head and Professor, Department of Electronic Science, CU).
17. Dipankar Biswas (1984) Some studies on solar cells and related systems (Professor, INRAPHEL, CU).
18. Syed Rafi Ahmed (1987) Electron Transport in submicron semiconductor samples (Lecturer in Physics, Acharya Prafulla Chandra College under CU).
19. Goutam Ghosh (1989) Studies on Gunn oscillators and associated problems (Professor, INRAPHEL, CU).
20. Debjani Bose (1991) Two dimensional electron transport in heterostructures and quantum wells (Teacher in Loreto School, Kolkata).
21. Sanghamitra Mukhopadhyay (1994) Transport of electrons in narrow quantum wells (presently at the Department of Materials, University of Oxford, UK).
22. Samita Gangopadhyay (2000) Studies on the electron transport properties of semiconductor quantum structures (Assistant Professor, Techno-India Technical Institution, Kolkata).
23. Madhumita Das (submitted in 2004) Studies on electron mobility in $Ga_{0.5}In_{0.5}P$ and $Ga_{0.5}In_{0.5}P/GaAs$ Quantum Wells (submitted under PK Basu after the demise of Professor Nag).

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 - (With ROY SK and CHATTERJEE CK) Microwave measurement of conductivity and dielectric constant of semiconductors *Proc IEEE* **51** 962
 - (With DAS P and PARIA H) Hall mobility and magneto-resistance of semiconductors due to hot electrons in high magnetic fields *Proc Phys Soc (London)* **81** 736-740
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