50 YEARS OF THE INSTITUTE

The foundation of the Institute of Radio Engineering and Electronics (IREE), Academy of Sciences of the Czech Republic, was closely connected with changes in the organisation of science in Czechoslovakia made by the Government in 1952, when the Czechoslovak Academy of Sciences (CAS) was founded. Preparation steps for the foundation of the Institute for Theoretical Radio Engineering (ITRE), CAS, the predecessor of the IREE, were made in 1953 by a small group headed by Sergej Djaďkov, one of the leading personalities of the Czechoslovak industrial research in electronics.

A pertinent decision of the Presidium of the CAS was made on 1 October, 1954 and that day is taken as the official date of the ITRE and also of the IREE foundation. The real work started on January 1, 1955 and in the same year, the ITRE was re-named to the Institute of Radio Engineering and Electronics (the Institute) of the CAS. Sergej Djaďkov was appointed the first Director of the Institute. A small group of experts from industrial research of stable oscillators and precise frequency and those active in applications of random processes and statistical methods in radio engineering came with Djad´kov to the Institute. Moreover, a number of individual experts joined the Institute and formed research teams in the fields of *circuit theory, precise measurements of time intervals and electromagnetic wave propagation*. So the initial main orientation of the research program was marked out.

At the end of 1955, there were 36 co-workers (including 16 researchers) in the Institute, one year later, the corresponding numbers were 71 (19) and in 1960 even 180 (30). In 1959, a group of researchers specialized in random processes left the Institute and joined the newly established Institute of Information Theory and Automation of the CAS.

In the first years of its activity the Institute was dislocated at 14 different places over Prague. A new Institute´s seat in Kobylisy was finished and opened only in 1961, which was a very important step for the development of its experimental research facilities. For example, the first etalon for precise time and frequency measurements with a stable crystal oscillator thus could be placed in a 14-meter deep and temperature-controlled well constructed in the building.

Better experimental facilities and experience of research teams of the Institute created necessary conditions for achieving important results in several research areas. Besides results in electromagnetic wave propagation and circuit theory, the Institute was successful in the evaluation of the Doppler effect during the flight of the first Sputnik, and Jiří Tolman, a leading personality in the research of *standard time and frequency*, encouraged several co-workers to pursue research in *quantum electronics* with the aim of developing a maser system. The start of the operation of the ammonia maser in 1963 represented Czechoslovak priority. Another success was a ruby laser built in the same year.

In the beginning of 1963, a new Director of the Institute, Václav Zima, was appointed. He made substantial changes in the Institute’s scientific program and its structure. The Department of Electromagnetic Wave Propagation was transferred to the Institute of Geophysics, CAS and, on the contrary, part of the former Laboratory of Optics of the CAS, engaged in the research of optical materials for the infrared spectral region, was included into the Institute. And later on, in 1965, one department of the Institute of Physics of the CAS, dealing with the research of ferroelectric single crystals and their electronic applications, was transferred to the Institute, where a new Department of Non-linear Dielectrics was set-up.

The above mentioned changes in the Institute’s scientific program reflected the world progress in the field of microelectronics, optoelectronics and quantum electronics. In order to stimulate these processes, a considerable part of the Institute’s capacity was focused on the research oriented towards semiconductor technology, optical communications and physics. Selected research activities that were pursued after 1965 and which formed the future development of the Institute are summarized below.

Circuit theory has been the field of research in the Institute since its establishment. At the beginning the research was devoted to the theory of chains of two-ports, to electrical filter theory and to the theory of non-linear circuits and oscillations. Later on the research was concentrated on discrete and digital signal processing, especially on digital filters, discrete Fourier transform, and spectral and cepstral analysis. In 1981, a small research group started to study the speech analysis, speech coding and speech synthesis. From the very beginning it cooperated with the Institute of Czech Language, the Institute of Information Theory and Automation of the Academy and with several industrial institutes. In 1987 the cooperating research teams were awarded the Czechoslovak Academy of Sciences Prize for their contribution to speech coding.

The efforts in *standard time and frequency* provided worldwide recognized results–for example, a method for accurate time comparison using television synchronizing pulses. In the pre-GPS era, this method, devised by Jiří Tolman, was used all over the world.

Another outstanding researcher, Věnceslav František Kroupa, cooperated initially with Jiří Tolman on the building-up of the Czechoslovak centre of standard frequencies. Later on he pursued his work in the group around Václav Zima, contributing significantly to the study of frequency synthesis and receiving international recognition. His book "Frequency Synthesis: Fundamentals and Measurements", published in 1973, was the first book in the world written about this field. In recognition of his contribution, he was awarded the Mach Medal of the Academy of Sciences in 2003.

Optoelectronics has been developing since the mid-sixties. The Institute's activities in this area began with the investigation into diffused GaAs-based radiation sources. The Institute was one of the few institutions in the world at that time investigating, designing and manufacturing GaAs electroluminescent numerical displays. The original display design, in the context with the emerging digital techniques, generated considerable interest abroad.

The investigation of physical principles of electroluminescent elements was pursued from 1967 to the end of 1980s. The Vapour phase heteroepitaxy of GaP was employed to manufacture GaP substrates for electroluminescent diodes in the red region of the optical spectrum. This technology was further improved by the employment of liquid phase epitaxy for the preparation of heterostructures. In 1979, the attention was shifted to semiconductor light sources for optical communications. The activities were concentrated on two directions: The first one was based on the AlGaAs /GaAs system for 0.8-μm window, and the second one on the InGaAs/InP system for operation in the 1.3- and 1.55-μm windows. In 1981, continuous light emission at 0.8 μm was achieved at room temperature with an AlGaAs/GaAs laser. In 1988, continuous operation was achieved with a laser for the 1.3-μm window, and a year later, with a laser for the 1.55-μm window.

A novel diagnostic technique, Secondary Ions Mass Spectroscopy (SIMS), was implemented in 1974 and proved to be very useful for explaining the mechanisms of ionization of atoms emitted from the surface of solids. The contributions of Zdeněk Šroubek to understanding charge transfer processes at surfaces have received international recognition, ever since. Other analytical methods suitable for electrical and optical studies of optoelectronic structures have also been systematically developed and employed. Among them, the most notable are Deep-Level Transient Spectroscopy (DLTS) and Low-temperature Photoluminescence (PL) spectroscopy.

In the field of *coherent optics*, the equipment and the experience gained in holographic recording were directed to the development of several special methods of holographic interferometry for the investigation of deformations and mechanical vibrations of various objects or revealing their shapes by holographic topography. Holographic diffractive gratings as an advantageous alternative to the gratings ruled mechanically were produced and supplied to industry for special optical devices. Original contributions to the theory of holographic imaging were made; the idea of focusing coupling gratings in planar waveguides represented the world priority.

In 1977, the development of *integrated optics*, i.e., the research of various waveguide elements for dividing, combining, controlling and processing optical signals directly at optical frequencies, started. Theoretical analysis of light propagation in planar and channel waveguides has been developed, particularly with respect to anisotropy of the substrate and to electrooptical and acoustooptical interactions. Methods for the design as well as preparation of lithographic masks were worked out to facilitate the experimental work.

At the end of 1970s, in agreement with world trends in optical communications, several teams in the Institute started to deal with the preparation and characterisation of optical fibers. At the end of 1980s, joined effort of the IREE and the Institute of Chemistry of Glass and Ceramic Materials of the CAS resulted into methodological and technical support of technologies for optical communications in Czechoslovakia. This support included – for example, physical models used for the control of preparation of graded-index fibers, unique devices for the measurement of the fiber diameter during drawing and for automatic control of this process. These results were supported by extensive theoretical and experimental research on light propagation in fibers for both communications and sensors, fiber characterization, and technology of fiber components. Emphasis was also given to the research on polarization-maintaining fibers with stress-applying parts.

The political changes in 1989 and the later division of Czechoslovakia had great impact on the CAS and its Institutes. A pertinent document proving the existence of the Institute within the Academy of

Sciences of the Czech Republic (ASCR) and signed by the President of the ASCR became effective on December 31, 1992. Of course, the research work went on since November 1989 all the time without any interruption. As early as in 1990, just at the beginning of the new era, an Institute's Scientific Council was elected as a body with an active share on managing the Institute and Viktor Trkal was appointed Director. Gradually, some changes in the research program arose – the emphasis was shifted back to basic research with the aim of achieving standards common in technologically advanced countries. The applied research was suppressed, also due to the collapse of the Czechoslovak electronics industry.

Through the first all-Academy evaluation process in 1992 the Institute passed with rather favourable results. Despite of the fact that the scientific programme was, in essence, approved, the number of employees was reduced by one third, which resulted in staff of 128 employees, including 68 researchers. Since then, the evaluations of the Institutes of the ASCR are being performed regularly on international level. Jan Šimša was appointed as the Director of the Institute in 1994, and after two terms in this position, he was succeeded by Vlastimil Matejec in 2002.

Since 1990 the research of the Institute has been concentrated on three research areas - *signals and systems*, *photonics*, and *materials research for optoelectronics*. Major achievements are described in some detail in the Review that follows. Here are mentioned only activities which have emerged or have been developed with special momentum after 1990.

In 1993, the *Laboratory of Technology of Optical Fibres*, a part of the former Institute of Chemistry of Glass and Ceramic Materials joined the Institute. This act made it possible to strengthen the Institute research in the field of optical fibers, because the Laboratory´s program has been focused on material research of optical fibers for communications and chemical sensing. Physicochemical principles of the fabrication of multilayered optical structures via the chemical vapor deposition and sol-gel methods have been investigated. On this basis, rare-earth doped active fibers and novel types of sensing fibers, such as sectorial fibers, inverted-graded index fibers, fibers based on soft optical glasses, have been prepared and investigated in collaboration with researchers at the Ecole Central de Lyon, France, and the University of Jean Monnet in Saint Etienne, France. Special polymeric and xerogel coatings sensitive to chemicals have also been investigated. Recently, microstructure fibers and special fibers with long-period gratings have been prepared in the Laboratory.

Advanced fibers produced by the Laboratory represented, to a great extent, a basis for the investigation of *non-linear fiber optics* in the Department of Communicatione Systems. The research into generation, amplification and non-linear propagation of ultrashort optical pulses in active fibers was carried out. Novel methods for preparing twin-core fibers were designed, the fibers were prepared and tested. Software tools for the analysis and design of erbium-doped, erbium-ytterbium-doped praseodymium-doped and Raman fiber amplifiers have been developed. These programs have been used for the optimization of rare-earth-doped fibers and for the analysis of transient effects in fiber amplifiers. They have also been integrated into commercial simulation packages by Optiwave Inc. (Canada).

Research into *surface plasmon resonance (SPR) sensors* started in the early 1990s. Initially, the research effort was mainly focused on theoretical study of surface plasmons and their experimental investigation by the attenuated total reflection method. The first SPR sensor developed at the Institute in 1992 was based on the attenuated total reflection method and angular scanning. Shortly afterwards, a fiber optic SPR sensor has been proposed. The concept of the optical fiber sensor has been further refined over the following years and resulted in a smallest SPR fiber optic sensor developed worldwide. SPR sensors based on integrated optical waveguides have also been investigated and laboratory prototypes of integrated optical SPR sensors based on ion-exchanged waveguides and spectral modulation have been demonstrated. In the late 1990s, the surface plasmon resonance phenomenon on diffraction gratings has been studied. Based on this research, a new research program aimed at multichannel SPR sensors using diffraction gratings has been initiated. In 2002, this program resulted in a unique multichannel SPR sensor based on spectroscopy of surface plasmons on an array of diffraction gratings, the first SPR sensor platform capable of performing over 100 measurements simultaneously. In collaboration with scientists at the Institute of Macromolecular Chemistry, Prague, and the University of Washington, Seattle (USA), Institute researchers exploited the unique SPR sensor platforms for the detection and identification of chemical and biological analytes relevant to environmental protection (pesticides), medical diagnostics (hormones, antibodies), food safety and security (chemical contaminants, toxins, bacteria). SPR sensors developed at IREE have provided a tool enabling research in biomolecules and their interactions carried out in collaboration with the Institute of Haematology and Blood Transfusion, Prague.

Several *diagnostic techniques* have been developed for the state-of-the-art characterization of semiconductor bulks, layers, structures and surfaces as well as glass materials. The capability of the DLTS spectroscopy has been enhanced considerably by a recent introduction of advanced equipment. The DLTS has been further extended by the development of admittance spectroscopy. Temperature dependent Hall effect measurements of semi-insulating materials are pursued in the range 7 K – 430 K on the built equipment with the closed cycle He-refrigeration system. Low-temperature PL spectrometer now enables us to make sensitive measurements with high resolution in a spectral range 300-5000 nm. The characterization capability has been further improved by a scanning electron microscope equipped with EDX system and recently extended by a home-made cathode-luminescence. The time-of-flight mass spectrometer has been developed to enhance the performance of the SIMS apparatus. Nanostructures and very thin layers of selected semiconductors are being studied by ballistic electron emission microscopy and spectroscopy, and also by a scanning tunneling microscope developed in the Institute.

Meta-stable states of DX centers were studied experimentally in cooperation with University of Manchester Institute of Science and Technology (UMIST), England. It was found that Sn-related DX center in AlGaAs exhibited considerably different dynamic properties from those of Si- and Te-related centers. A new mechanism of degradation during operation of commercial high-brightness GaP:N green light emitting diodes has been found by DLTS and electroluminescence spectroscopy. This research was done in co-operation with Siemens, Germany.

The self-consistent Green's function technique, within the framework of the tight-binding approach, has been developed and tested, which allows realistic calculations of the electronic structure of strongly localized defects in III-V compounds to be made. The technique has been used for the analysis of localized modes associated with defects in *photonic crystals* in co-operation with the University of California, Irvine, and Lisbon University. Theoretical research of photonic crystals is being concentrated on random active media, analysis of scattering properties of cylindrical left-handed materials, and on non-linear effects.

Besides the research, education of postgraduates has taken place in the Institute since the very beginning. First students became regular co-workers of the Institute in 1959 and all the time till now most of key Institute’s researchers obtained their post-graduate education in the IREE. Since 1999 young co-workers have been pursuing their PhD studies within the framework of common accreditation with Universities. The Institute has common accreditation with Charles University and Czech Technical University in Prague in six research directions.

Research and education pursued in the Institute have lead to numerous papers. Over the past 50 years, scientific staff of the Institute has published almost 1400 papers in international journals and 36 monographs in foreign languages. Moreover, outstanding scientific reputation of the Institute is reflected in organising many conferences, symposia, colloquia, workshops and seminars, both national and international. In the field of circuit theory besides six international summer schools, the Institute organised the 6th European Conference on Circuit Theory and Design in 1985. Its Colloquia on Circuit Theory, which have taken place more than 600 times, have gained high reputation. The biggest international scientific meeting organised by the Institute was the 23rd General Assembly of the Union Radio-Scientific International in 1990. Other major events were the Conference of Radiative Recombination and Related Phenomena in III-V Compound Semiconductors in 1979, the 7th IEEE International Symposium on Spread Spectrum Techniques and Applications in 2002 and the European Conference on Integrated Optics in 2003.

This brief overview demonstrates that the Institute of Radio Engineering and Electronics, ASCR is capable of achieving internationally recognized results within its fields of activity, contributing to the advance of science and exploiting it for benefits of society. Let us wish its scientists and all their co-workers every success in their future endeavours.

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