ON THE OCCASION OF 75TH ANNIVERSARY OF FULL UNIVERSITY PROFESSOR, CORRESPONDENT MEMBER OF THE ACADEMY OF SCIENCES OF MOLDOVA TEODOR SHISHIYANU

On June 11, 2008, Teodor S. Shishiyanu, Correspondent Member of the Academy of Science, Professor, Dr habilitat, Head of the Department of Microelectronics and Semiconductor Devices for 24 years (1981-2004), Scientific Director of International Center of Modern Technology for Study and Research of Technical University of Moldova, Laureate of the National Prize in Science and Technologies, founder of Microelectronics Specialization in the Technical University of Moldova, turning 75 years of age.

His 75th birthday is an important day for scientific community of Moldova to share our admiration for our excellent colleague and outstanding scientist. Professor Teodor Shishiyanu is specialist in physics of semiconductors and dielectrics, microelectronics and semiconductor devices, including technology of diffusion, ion implantation and rapid photothermal processing, reliability and degradation of micro-nano-electronic devices.

Professor T. Shishiyanu is one of initiators of international collaboration with many scientific groups from different Universities and Research Centers, such as the Ioffe Physical Technical Institute and Institute of Semiconductors of the Russian Academy of Sciences (St.-Petersburg, Russia), Essex University (Colchester, UK), Hallam University (Sheffield, UK), Polytechnical University (Bucharest, Romania), Clemson University (USA), University of Applied Sciences (Germany), National Institute of Telecommunications Paris (France), Riga Technical University (Latvia), etc.

The present paper illustrates some aspects of scientific investigations of Professor Teodor Shishiyanu together with the research of Professor Rajendra Singh (USA) in order to outline the value of the obtained results in the context of world science as well as to state again that truth science is unique.

Several aspects of scientific investigations in collaboration with Professor Rajendra Singh (USA)

Professor Rajendra Singh (USA) and Professor Dr. Hab. Teodor Shishiyanu (Moldova) are well known in the scientific world as highest rank specialists in domain of physics and technique of materials and semiconductor devices, solar cells and nanotechnologies.

Professor R. Singh and Professor T. Shishiyanu are well known from their scientific publications in the period of 1963-1985, and from 1985 to 2005 they have effectuated scientific investigations on the same scientific domain separately.

In 2005 Professor T. Shishiyanu proposed to Professor R. Singh a joined scientific Project in the frame of CRDF-MRDA scientific association between the USA and Moldova named “Modern and low cost nonconventional technology with Rapid Photothermal Processing for Si- solar cells”. Professor R. Singh immediately accepted the invitation for collaboration and the joined Project completing the Projects name “Modern and Low cost Nonconventional Technology with Rapid Photothermal Processing for Si-bulk and Thin Film Solar Cells”.

The Projects proposal was submitted and accepted as Project (MOE2-3052-CS-03) for 2005-2006.

Professor R. Singh in 2005 visited Chisinau Technical University of Moldova, where for the first time he met Professor T. Shishiyanu. Professors participated with scientific reports at International Conference ICMCS – 2005 in Chisinau.

The review of publications of Professors R. Singh and T. Shishiyanu confirms that both Professors have worked parallel more than 20 years in the same scientific directions and in the most cases the results and conclusions of their scientific investigations are similar. Therefore, from the first meeting they start their friendship and fruitful collaboration.

Biographical data of Professor R. Singh and Professor T. Shishiyanu are presented below.

Professor Rajendra Singh received the B.S. degree from the Agra University, Agra, India, in 1965, the M.S. degree in physics from the Meerut University, India, in 1968, the M.S. degree in physics (thesis on superconductivity) from the Dalhousie University, Halifax, NS, Canada, and the PhD degree in physics (dissertation on solar cells from McMaster University, Hamilton, ON, Canada, 1979). In 1979 he was an Assistant professor at the University of Waterloo, Canada (1979), at Colorado State University (1980), a Senior Scientist and worked on amorphous silicon solar cells and thermoelectric devices (1981); In August 1982, he joined the University of Oklahoma Norman as Associated Professor, Professor (1986) and Director of the Microelectronics Laboratory (1987-1990). In January 1991, he joined Clemson University, Clemson, USA as the first D. Houser Banks Professor (1991-1996), Director of the Material Science and Engineering Program. Since November 1997, he has been appointed as a Director of the Center for Silicon Nanoelectronics. He has published over 260 papers in various journals, over ten books, and conference proceedings in the field of solar cells, rapid thermal processing, semiconductor manufacturing and nanotechnology. He is editor or co-editor over fifteen conference proceedings. He served as a guest editor of special issues of IEEE Transactions on Electron Devices (1992, 1998, 2002, 2006). He has presented over 60 keynote and invited talks in various conferences. He has many honors and Excellence Awards. He is a Fellow of the Society of Optical Science and Engineering American Association of Advancement of Science and ASM International, the Materials Information society.

Professor T. Shishiyanu received Diploma from Pedagogical School, Cahul, Moldova (1952); Diploma from the Pedagogical State Institute, Tiraspol, Moldova (1958), the PhD degree in physics of semiconductors and dielectrics from the Institute of Semiconductors of the Academy of Science of the USSR, St.-Petersburg (1961-1964, post graduate, 1964-1965, researcher, 1965 – PhD). In 1965 he was invited to Chisinau Polytehnical Institute, now Technical University of Moldova (TUM), where he worked as Senior Lecturer (1965-1967), Associate Professor (1968-1980), Professor (from 1980 to present); Head of Department of Microelectronic and Semiconductor Devices for 24 years (1981-2004) and since 2004 - Scientific Director of International Center “Modern Technologies for Study and Research”, UTM. In 1970-1971 he worked as an Invited researcher in the Essex University, Colchester, UK; in 1975-1978, a researcher in the Ioffe Physical-Technical Institute, St.-Petersburg; in 1982, for 4 months, a researcher in the Budapest Technical University, Hungary. In 1995 he received Diploma of Member Correspondent of the Academy of Sciences of Moldova. He has over 240 publications in different journals, 5 books, 5 patents, and over 60 presentations at International Conferences. He is scientific supervisor of 15 PhD dissertations, over 30 MSc and more than 150 License Diploma in Microelectronics and Semiconductor Devices. He was organizer and coordinator of 5 International Conferences “Reliability and degradation of Semiconductor Devices” (1982, 1986, 1992, 1996, 2000). Honors and awards: The State Premium in Science and Technique (1983), Governmental Medal “Meritul Civic” (1994), CEng. and Fellow of IEE, UK, (1995), Medal “Dmitrie Cantemir” of the Academy of Science of Moldova (2003) and other distinctions.

The review of selected scientific publications of Professor T. Shishiyanu and Professor R. Singh is presented below.

The majority of publications of the Scientific School of Professor R. Singh and the Scientific School of Professor T. Shishiyanu are in domain of Advanced Technologies of semiconductors and dielectrics with Rapid Thermal Processing (RTP). Rapid Thermal Processing of semiconductors and dielectrics based on incoherent radiations, the source of thermal and optical energies is emerging as key low thermal budget processing technique for the fabrication of advanced semiconductor devices [1-42].

In the late seventies integrated circuit researchers investigated several thermal–processing technologies as an alternative of conventional furnace processing named Rapid Thermal Annealing (RTA), or Rapid Thermal Processing (RTP). The first paper dealing with the use of low-thermal massgraphite heater for annealing GaAs ion-implanted wafers was reported in 1977 [1]. In 1980, Nishiyama and co-workers [2] used halogen lamps as a continuous source of radiation to anneal boron-implanted Si for a very short time (6 sec). The first applications of RTP in manufacturing have been realized by P.H. Singer in technology of titanium silicide fabrication [3]. In that time most of researchers attributed low-thermal massleading to high heating–cooling rates as the only difference between RTP and conventional furnace processing (CFP). In 1985 R. Singh pointed out the reduction of cycle time and process activation energy as the two distinct advantages of RTP over CFP [4].

In 1985-2005 Professor R. Singh and co-authors demonstrated the priority of RTP for semiconductor devices manufacturing. For obtaining of improved performance, reliability and yield of any semiconductor devices, use of homogeneous microstructure is a necessity.

Comparative study of dielectric formation by furnace and rapid isothermal processing has shown that the dielectric properties of silicon dioxide and tin oxide on Si formed by rapid isothermal processing are superior compared to furnace processing [6,7]. RTP and conventional furnace heating were used to study the electrical, structural, and mechanical of characteristics of these films and the results of the two processes compared. By spreading resistance analysis, stress measurements, X-Ray photoelectron spectroscopy, and High-frequency C-V methods, the superior structural, mechanical, and electrical properties of the PSG films on Si substrates have been demonstrated [9, 10, 12]. It was shown that by using variable heating and cooling rates of RTP, the thermal stress can be minimized, and the desired performance of the devices fabricated by RTP can be improved [16].

Deposition of high dielectric constant materials by dual spectral sources RTP assisted metalloorganic chemical vapor deposition has shown the highest dielectric constant and the lowest leakage current density reported to date [18]. It was demonstrated how the rapid thermal processing can be a dominant semiconductor processing technology in the 21st century [22].

Enhanced diffusion and improved device performance have been obtained by using dual spectral source Rapid Thermal Processing. High energy VUV photons in conjunction with infrared and visible photons resulted in enhanced diffusion and improved the bulk properties of silicon substrate. High energy photons from VUV region to about 800 nm result in a decrease in the bond dissociation energies of the molecules, since they are in electronic excited states, higher activation of dopants, reduction of activation energies, enhanced phosphorous gettering and overall reduction of the recombination-generation centers in silicon [24]. It was shown that the materials and devices processed by RPP are better than those processed by other thermal processes; the manufacturing science, operating principles of RPP and experimental results shown its role in future process integration [26].

It was demonstrated that quantum photo-effects dominated rapid photothermal processing can provide higher throughput, higher performance and higher reliability of semiconductor devices than any other thermal processing technique [28]. By rapid thermal processing high dielectric constant gate dielectrics for sub 70 nm silicon CMOS technology have been obtained [30]. The impact of single-wafer processing on semiconductor manufacturing and fundamental advantages of Single-Wafer Processing over batch processing are reduced cycle time, reduced defects and reduced process variations [32]. The effect of interfacial layers on high-performance gate dielectrics processed by RTP-ALD for in situ deposition, and annealing provide excellent leakage, capacitance, and reliability of the high-k dielectrics [34].

At the same time, in 1985 - 2008 Prof. T. Shishiyanu and co-authors published more than 240 papers and 5 books concerning the RTP and RPP technology for semiconductor device fabrication. The radiation-enhanced diffusion has been investigated by RTP of atoms in metal-semiconductor contact. By RTP the characteristics and quality of GaAs - Shottky diodes and *p-n* – junctions were improved [5]. Applying the numerical methods, the impurity profiles of radiation-enhanced diffusion by rapid thermal annealing have been calculated [8].

By RTP, the ultra-shallow and abrupt impurity profiles in Si, GaAs and InP for MESFET transistors were obtained [11]. The enhanced diffusion of Zn in GaAs and InP was successfully realized by RTP [13]. The possibility of formation of semiconductor device properties in special CMOS transistors by RTP enhanced diffusion was demonstrated [14]. Zn low-temperature diffusion in GaAs and GaP was performed by RTP [15]. By RTP, shallow, less than 300 nm *p-n* junctions in Si, GaAs and InP were obtained [17, 19].

The essential improvement of the quality and reliability of GaAs - Shottky diodes, avalanche diodes and components of Si – integrated circuits was realized by RTP [20]. The RTP and enhanced diffusion is presented as non-conventional technology for different devices in microelectronics [21]. The influence of RTP on SiO2 anodic grown films and the optimization of Si-MOS and CMOS transistor parameters by ion implantation and RTP have shown the high potential of RTP application in industrial manufacturing technologies for Si-MOS and CMOS [23, 25, 36].

The RPP Technology, the mechanisms and physical-mathematical models of enhanced diffusion of impurities in semiconductors, as well as application of RPP in Microelectronics and semiconductor device application, are analyzed in book [27]. GDOES method is applied for the investigations of the surface junctions in Si, GaAs, InP obtained by RTP and enhanced diffusion [29].

The surface enhanced diffusion of P and B in Si under RPP is explained by the kick-out and vacancy diffusion mechanisms, taking into consideration the time dependence of the surface impurity concentration and the concentration dependence on the diffusion coefficient [31]. The influence of the non-thermal factors on phosphorous diffusion under pulse RTP is analyzed in [33]. RPP technology for gas sensor applications based on oxide semiconductors is presented in [35].

Since 2005 Professor R. Singh and Professor T. Shishiyanu began common investigations in development of RTP technology for solar cells and micro-nanoelectronic device fabrication in the frame of CRDF-MRDA Project named “Modern and Low cost Nonconventional Technology with Rapid Photothermal Processing for Si-bulk and Thin Film Solar Cells” (MOE2-3052-CS-03). The nonconventional technology with rapid photothermal processing for Si-solar cell applications has been elaborated and investigated, including the enhanced diffusion of phosphorus in Si, oxidation-passivation, coating and metallization. Si-n^+-p-p^+-solar cell structures, ZnO/Si heterojunction and nanostructured ZnO have been obtained and studied; the computerized RTP system has been improved and implemented. The priority of RTP-RPP technology was experimentally demonstrated: the RTP-diffusion coefficient is higher by 2-4 orders of magnitude, the thermal budget is lower by 2-3 orders of magnitude, and the duration of the technological processes of solar cell fabrication is significantly shorter compared to conventional furnace technology. Therefore, this technology is of interest for solar cell fabrication in Moldova.

Meeting of Moldavian specialists with Professor R. Singh, Director of Center for Silicon Nanoelectronics, Clemson University (USA) in Moldova.

Professor R. Singh visited Moldova in October 2007 with the proposal of organization in Moldova the Solar cell production based on new technologies supported by USA investors.

The official meeting was organized by TUM, with participation of the Academy of Sciences of Moldova and factory “Mezon”: Professor R. Singh, Director of Center for Silicon Nanoelectronics, Clemson University (USA); Vice-Rector TUM Professor Dr. Hab. V. Dorogan; Academician D. Ghitu, Director of IEETI (ASM); Professor Dr. Hab. T. Shishiyanu (TUM), Dr. S. Shishiyanu (TUM); Dr. I. Sobor, Director of Center of Renewable Energy (TUM); Dr. A. Catan, Director of factory “Mezon”.

All the participants proved that solar cell manufacturing is of high necessity in Moldova but the high cost of the photovoltaic energy compared to electric energy now provokes some difficulties in the implementation. But in the future the priority has to be of photovoltaic energy.

The collaboration continues in fundamental and applicative investigations of Technology with Rapid Photothermal Processing for fabrication of silicon solar cells and TiO2/SiO2/Si thin film solar cells [37, 38, 40]; RPP of semiconducting oxide nanostructures on the Si substrates for solar cell applications [39]; Thermal budget for Rapid Photothermal Processing solar cell fabrication [41]; The mechanism and role of thermal - quantum factors in Rapid Photothermal diffusion of P in Si, to be published [42].

At the end we would like to express our gratitude to Professor Teodor Shishiyanu for his fruitful efforts in developing semiconductor science in Moldova and wish him many new successes and discoveries for the years to come.

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