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biography and bibliography

Professor YURI NIKOLAYEVICH VERSHININ (1932–2006)*

Professor Vershinin was born on 10th January 1932 in Novosibirsk. He finished his schooling there, graduated from the technology department of the Novosibirsk Construction Engineering Institute in 1954 and completed his studies at the Novosibirsk Institute of Electrical Engineering (currently Novosibirsk State Technical University) in 1966. From 1955 until 1958 he worked at the Novosibirsk Building Materials Factory where he rose to the position of Chief Engineer. In 1958 Professor Vershinin started his postgraduate studies at Novosibirsk Construction Engineering Institute and in 1962 he defended his dissertation for a Candidate of Science degree: "The effect of low-frequency electric fields on structurization processes during gypsum cement solidification."

In 1961 he organized and headed the laboratory of electrical concretes at Siberian Research Institute of Power Engineering (SRIPE). Four laboratories branched out from this laboratory over 10 years and formed the department of electrophysics.

Professor Vershinin defended his doctoral thesis in high-voltage engineering "Energy analysis of the pulse strength of solid dielectrics," at Leningrad Polytechnic Institute (currently St. Petersburg State Polytechnic University) in 1970. From 1973 to 1979 he worked as the deputy director of science and the head of the electrophysics department at SRIPE and he became a professor at Novosibirsk Institute of Electrical Engineering in 1972.

For his major contribution to the development of power engineering and training researchers, in 1974 Professor Vershinin was awarded the Order of the October Revolution.

In 1979 Professor Vershinin was appointed Director of G.M. Krzhizhanovsky State Institute of Power Engineering (Moscow) where he worked until 1986.

For his contribution to power engineering in the country, in 1984 he was awarded the Order of the Red Banner of Labour.

In 1985 Professor Vershinin and his colleagues won the USSR State Prize for developing and implementing industrial production of concrete-based resistors to protect substations and large national power grid installations against short circuits.

In 1986 he moved to the Ural Branch of the USSR Academy of Sciences (Ekaterinburg) where he was Vice-Chairman until 1993, and a member of the Presidium of the RAS Ural Branch until 2001.

In 1987 he organized the dielectric physics laboratory at the Institute of Electrophysics, Ural Branch of the Russian Academy of Sciences, which he ran throughout his time at Ekaterinburg. In 1998 he also organized and headed a joint problem laboratory at the Institute of Electrophysics and Rosaviacosmos. Specialists from the laboratory conduct basic and applied research in rocket and space engineering, and interdisciplinary sciences.

Professor Vershinin was elected a Corresponding Member of the Russian Academy of Sciences in 1987 and of the Institute for Catalan Studies in 1992.

Professor Vershinin tutored 29 Candidate of Science students, 8 of whom went on to defend doctoral theses. He is the author or a co-author of three monographs, a textbook, 128 papers and 28 Certificates of Authorship and invention patents.

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Public work and teaching

Vershinin's parents were well-educated, cultured people. His mother was involved in public work. His father was a well-known specialist in radio engineering and communications who, in 1947, was slandered and convicted. His name was not cleared until 1956.

As the son of a political prisoner, Professor Vershinin was not able to join the higher education institution of his choice after school. He did not enter an electrotechnical or physics institute, as he had wished, but graduated from the chemical engineering department of a construction institute.

After graduating from the institute in 1954 and working in factories in Novosibirsk, Professor Vershinin started a postgraduate course and defended his dissertation for a Candidate of Science degree in 1962. From 1960 to 1962 he worked for the chair of building materials at the Construction Institute and became a lecturer.

In 1972 Professor Vershinin became a lecturer at Novosibirsk Electrotechnical Institute where he gave the course, "Basic physics of high-voltage techniques," supervised the work of postgraduate students, and acted on the theses board.

From 1980 until 1989 he was a member of the "Strong Pulsed Power" and "Scientific Fundamentals of Electrophysics and Electrical Engineering" committees at the Academy of Sciences, and he was also a member of the "Development of Power and Electrical Engineering" committee at the USSR State Committee for Science and Engineering from 1982 to 1990.

Professor Vershinin served as a member of the USSR Committee for Power Engineering for UNESCO (1983-1988) and as an authorized representative of the USSR at the Council of Socialist Countries "Cryogenic Power Engineering" committee (1980-1987).

After his arrival in the Ural region (1987), Professor Vershinin was assigned the post of Vice-Chairman of the Ural Branch of the Academy of Sciences and performed a broad scope of work organizing both branch and some new institutes by negotiating with local and central authorities and the scientific community. At the same time he was involved in establishing the Electrophysics Chair at the Ural Polytechnic Institute where he gave the course, "Dielectric Physics" until 2001.

From 1987 he was a member of the Doctoral Thesis Board at the Ural Polytechnic Institute (until 1999) and then at the Institute of Electrophysics (until his death in 2006). Throughout this period he supervised postgraduate students.

In addition to his scientific work, Professor Vershinin enjoyed alpine skiing and travelling. He also collected and machined interesting stones and pieces of wood, played the piano, and was generally a sociable and well-humoured colleague. All these features: great learning, a profound professional knowledge and inexhaustible benevolence, attracted people who hold dear the memory of this wonderful person.

Scientific interests and contribution to electrophysics†

The contribution made by Yuri Nikolayevich Vershinin, who was a Corresponding Member of the Russian Academy of Sciences, to the science of the nature of electrical breakdown in solid dielectrics further proves the thesis that despite growing specialization, the most interesting results are obtained where different sciences meet.

Although he did not have the chance to fulfill his dream of becoming a physicist, Professor Vershinin graduated from Novosibirsk Construction Engineering Institute and qualified as a specialist in the physics and chemistry of building materials. After graduating from the Institute, he worked at Novosibirsk Concrete Product Plant for three years and worked his way up to the position of Chief Engineer at the plant.

In 1958 Professor Vershinin joined the internal postgraduate course at Novosibirsk Construction Engineering Institute. His inclination towards the study of physical processes led to the topic of his thesis for a Candidate degree: "The effect of low-frequency electric fields on structurization processes during gypsum cement solidification."

In this work Professor Vershinin theoretically substantiated the possibility of using a new electric field method to control the processes involved in the solidification of gypsum cement [1, 2, 3]. It included a detailed study of the crystallization of gypsum stones by contact and non-contact application of an electric field. His work extended traditional studies of building materials science: Professor Vershinin was the first to widely use electrical, optical and electroacoustical methods along with standard techniques. For example, he determined the structurization kinetics of gypsum stones using specially designed high-sensitivity electroacoustical equipment. Professor Vershinin proposed referring//linking//contrasting the time before the onset of gypsum solidification to the moment the gypsum structure begins to form, reflecting more correctly the physical essence of the processes. He found that the electric field causes electrical orientation of the crystals in the direction of the field leading to the electrooptical effects of dichroism and double refraction. He also found that the application of an electric field leads to the electrophysical effects of cataphoresis and electrical orientation, which influence the physical-mechanical characteristics of gypsum stones.

One of practical results of his study was the possibility of using electric conductivity measurements for automatically controlling gypsum production processes.

Professor Vershinin had a good chance to extend his studies when he moved to the Siberian Research Institute of Power Engineering (SRIPE) headed by Professor V.K. Scherbakov, who sagaciously recognized his huge potential and soon organized a laboratory of electrical concretes for him. The laboratory worked in two directions simultaneously:

— studying electrical properties of new formations of cement stones

† A brief report by Bernatsky A.F., Ushakov V.Ya. and Tselebrovsky Yu.V. at the conference "Electrophysics of materials and installations" dedicated to Yu.N. Vershinin. Novosibirsk, January 9-12, 2007.

— developing a new composite material: current-conducting concrete.

The scientific activities of Professor Vershinin and his colleagues in the first direction resulted in a new insulating concrete, with high, stable dielectric and mechanical properties. Their experimental and theoretical studies led to the creation of this material and the development of some high-voltage insulating structures for power transmission lines and substations rated 0.38 to 500 kV.

The development of the insulating concrete was possible thanks to the phenomenological theory of the electrical strength of solid dielectrics developed by Professor Vershinin in the 1960s [5]. This theory allowed the electrical strength of clinker minerals and of new crystalline-hydrate formations of cement stones to be the quantitatively estimated. Theoretical values of the pulsed electrical strength of crystalline hydrates of cement stones were confirmed experimentally. Scientific research allowed the electrical properties of individual components of the concrete cement (electrical conductivity of solid phases in cement stones and moisture in cement pores; electrical strength of air in pores and capillaries; electrical properties of rock — filler) and of the concrete as a whole to be established. This information was used to recommend cement binders, concrete composition, and processing conditions. All this served as the basis for the development of insulating concrete and the structures of this concrete [6-10].

Production prototypes of resistors made from the current-conducting concrete (called "betel") were manufactured. In developing betel, Professor Vershinin broke all the rules of concrete strength theory. According to this theory, graphite and other weakly adhesive fillers were inadmissible in the cement-sand composition. The use of polycrystalline graphite as the filler and, later, the addition of soot to the composition did not just fail to destroy the electroconcrete, but allowed products to be created with acceptable mechanical strength. Professor Vershinin laid the foundations for the theory of the electrical conductivity of betel, which were developed later by his colleagues M.S. Dobzhinsky, V.P. Pogorelov and others. The technology for producing betel resistors was also advanced simultaneously by Professor Vershinin's colleagues L.N. Repyakh, L.E. Vrublevsky, R.V. Manchuk, N.A. Pugachev and others.

It should be emphasized that the large-scale work on the development and the introduction of betel resistors was possible thanks to practical activities undertaken by Professor Vershinin. His great erudition in different areas of knowledge, practical skill and friendly attitude to people along with his other characteristics allowed him to rapidly gather together a multidisciplinary team to work on betel resistors and their introduction to electrical power engineering. The State Prize awarded to Professor Vershinin and his team was worthy recognition of their important work.

Simultaneously with the work on the introduction of betel resistors and insulating concrete structures, Professor Vershinin continued his work on electrical strength theory. As betel (M.S. Dobzhinsky, R.V. Manchuk, L.N. Repyakh) and the insulating concrete (V.A. Chunchin, A.F. Bernatsky) became independent research projects with the establishment of the corresponding laboratories at SRIPE, Professor Vershinin focused on problems associated with electrical breakdown. A new direction emerged. While Professor Vershinin was exploring the problem of the electrical strength of solid dielectrics, workers of the electrical breakdown laboratory headed by E.V. Yanshin were working on the breakdown theory of liquids. With Professor Vershinin as their supervisor they rejected the theory of impact ionization, which some investigators tried to adapt—along with gases—to liquid dielectrics. A new theory was advanced based on the initiation of the discharge in gas micropores, which are always present or are formed on application of a field.

The contemporary physical data (specifically on the band structure of solids), the existing classical and quantum-mechanical theories of impact ionization in solids, the basic provisions of the theory of combustion, detonation and explosion and their use to describe breakdown processes in different dielectric media led Professor Vershinin to two important conclusions:

1) The description of breakdown in solid dielectrics as a consequence of the impact ionization of the valence band should be revised.

2) The most promising consistent physical presentation of breakdown in solid dielectrics consists of a step-by-step consideration and description of all breakdown phases in their time and spatial sequences.

In his first studies into the breakdown of solid dielectrics Professor Vershinin developed the so-called "energy approach," which established the relationship between electrical strength and structural parameters of solids [5]. He introduced the parameter of the specific energy of the channel formation, which served as the link between the main high-voltage characteristic of dielectrics —electrical strength— and the structural and energy parameters of solids.

Later, Professor Vershinin and his colleagues focused on the processes leading to the formation and propagation of electrical breakdown channels. In their summarizing monograph [11] they present physical models of these processes and describe them in an analytical form. This makes it possible to establish the relationship between parameters of the energizing voltage, space–time characteristics of the discharge, thermodynamic properties of the substance in the discharge channel, and individual properties of dielectrics. We will now turn to the basic conclusions of their study.

Electron conduction and the primary channel in solid dielectrics

The analysis of electronic processes in near-electrode regions led Professor Vershinin to the concept of a breakdown "primary channel" in solid dielectrics. The mechanism responsible for this primary channel is related to two types of instability that develop in the system of conduction electrons under the action of a strong electric field: the instability of the electron velocity distribution function, and spatial superheating instability. Intrinsic charge carriers penetrate the conduction band by electrostatic (field) and impact ionizations of impurities, while extrinsic charge carriers penetrate by injection of electrons from the cathode and holes in the anode.

Instability of the first type is followed by the formation of “runaway” electrons, that is, electrons whose energy (which is accumulated in the electric field) is higher than that from interaction with lattice vibrations. This is simply the condition of impact ionization in the one-electron approximation. In the many-electron approximation, the impact ionization criterion is determined from the condition that the ionization process dominates over the recombination process or other processes leading to a decrease in the number of conduction electrons. Accordingly, the electron distribution function changes and “runaway” electrons appear at energies W (0.1 eV). For electrons to be capable of impact ionization, their kinetic energy should increase by two orders of magnitude (up to W_{cr} (7-14 eV).

Professor Vershinin was among the first to remark on a set of results obtained by different researchers concerning the behaviour of solid dielectrics and wide-gap semiconductors in strong electric fields. Those results called into question the possibility of impact ionization of the valence band. Essentially these results can be summarized as:

— all dielectric crystals, including alkali halide (AH) crystals, have sufficiently narrow conduction and valence bands;

— valley-to-valley overlapping of the first conduction band is not generally observed (except at energies where the band non-parabolicity is of principal importance). For example, conduction electrons in NaCl crystals can acquire a maximum energy of only ~2 eV in the [100] direction;

— direct band-to-band transitions of electrons in electric fields were not detected experimentally in wide-gap semiconductors and dielectrics.

Really, only one experimental fact counted in favour of impact ionization as the basis of the electrical breakdown mechanism in solid dielectrics: the good agreement between measured and calculated (in terms of the impact ionization theory) values of the electrical strength of AH crystals.

To resolve this contradiction, Professor Vershinin analyzed the phenomenon of superheating electrical instability (SEI) in crystalline dielectrics. In semiconductor physics this term refers to processes leading to an inhomogeneous spatial distribution of the field and the current over samples. A necessarycondition for SEI is a negative differential conduction in samples.

Under real breakdown conditions, primary conduction electrons induce local centers of the volume discharge. Any fluctuation of the volume discharge gives rise to corresponding fluctuations in the current and field. Sources that initiate (trigger) fluctuations include inhomogeneities in the impurity distribution, structural defects that are much longer than the free path (dislocations, twins, crystallites, etc.) and inhomogeneities in the field distribution determined by the electrode geometry.

S-type and N-type instabilities are most probable in the near-electrode regions and the bulk of dielectrics respectively. Of the numerous SEI mechanisms, the monograph [11] discusses the most interesting (in the context of the problem to be solved) case when energy and momentum are scattered by optical polar vibrations. This is where the development of SEI and breakdown criteria in the classical and quantum-mechanical theories have much in common.

S-type superheating instability criteria define the intervals of electric fields and electron temperatures, above which conduction electrons tend towards current pinching. This process is accompanied by a rise in the conduction current density in a local area of dielectrics. This rise may be due to the increase in both the concentration and the mobility of charge carriers.

Impact ionization criteria define the conditions for the change in the velocity distribution function of conduction electrons caused by “runaway” electrons. As a result, the distribution-function-averaged mobility of charge carriers increases. These criteria characterize different aspects of one and the same process, which is based on the heating of conduction electrons in strong electric fields. As emphasized in [15], the first criteria determine the character of the overall process in the system of conduction electrons when a strong electric field is applied to dielectrics, while the second criteria define the conditions of its realization. Therefore, the quantitative agreement of these criteria is not accidental. It should only be remembered that because of the qualitative difference of energy band parameters in semiconductors and dielectrics, in the latter we are dealing with the impact ionization of impurity levels.

Pinching of the electron conduction current near electrodes (due to emission, and caused by electrostatic and impact ionizations of shallow impurity levels) leads to nucleation and propagation of the primary channel. Since the process is related to phase transformations of the substance in the channel, the power density should be higher than some critical density (10^5-10^6 W/cm^2 for AH crystals) for the process to proceed. An intermediate step in the evolution of the primary channel is the formation of a melt in the channel. As breakdown develops, current flow should lead to the heating of the melt up to the boiling point and the appearance of a gas phase, which is ionized and forms a plasma channel. These processes are practically irrespective of the initiating electrode polarity and, consequently, the space-time characteristics of the primary channel from the cathode and the anode are identical, as reported in optical and electron-optical studies.

The development of cathodic and anodic breakdown channels

The next step of the breakdown—the channel propagation to the opposite electrode—is so sensitive to the polarity of the initiating electrode that Professor Vershinin was able to use two considerably different groups of processes to describe it: electron-thermal processes for a discharge from the cathode, and electron-detonation processes for a discharge from the anode.

For a cathode discharge, the contact between the dielectric and its melt is a point injector of conduction electrons. The value of the injection current is limited not by the width of the potential barrier and the field intensity, but by the ability of melt ions to transport electrons to the interface and the parameters of the volume charge injected through this contact into the solid dielectric. The injection rate of charge carriers determines one of the most important parameters of discharge channel propagation, namely the power density at the interface between the solid dielectric and its melt. Another important parameter is the intensity of the superheating instability in the system of "intrinsic" electrons.

For quantitative descriptions of electron and thermal processes, which underlie the development of the cathodic channel, Professor Vershinin considered in detail the dependence of solid dielectric melt properties on the parameters, which alter during breakdown development. He adopted the parameters mostly from the analysis of experimental data available in the literature on the pulsed breakdown of solid dielectrics.

Careful analysis of a large volume of experimental data led Vershinin to the conclusion that the processes involved in the development of the anodic channel were more like processes during the detonation of explosives and the laser breakdown of gases, than like the processes underlying cathodic channel development.

The development of the anodic channel is characterized by the following features:

— the velocity is supersonic and constant;

— the mass velocity in the energy release zone behind the shock wave front coincides with the propagation direction of the breakdown channel;

— the thermodynamic parameters of the substance in the energy release zone are much larger than in the rest of the channel.

He showed that all the processes in the energy release zone are due to the intensive injection of valence electrons from the shock compression region. This led to the mechanism by which the anodic channel of the pulsed breakdown propagates being named electron detonation. It could be described in quantitative terms by experimental and calculation-theoretical methods from studies of other types of detonation.

Intensive injection is explained by two factors:

a) a strong electric field formed at the head of the channel, which acts as a pointed anode with an extremely small radius (10^5 m);

b) shock compression of phase dielectrics at the interface, reducing the potential barrier for injection of valence electrons.

The high density of the injected current causes a vigorous liberation of energy behind the interface.

These factors are responsible for quantitative and qualitative differences between electron detonation and the detonation of explosives.

In the case of the explosives, the shock wave, which initiates the explosive transformation of the substance, is maintained in turn by the exothermal reaction energy liberated behind the wave front. The value of this energy and, hence, the shock wave velocity are individual characteristics of explosives. The shock wave velocity is not over 10^6 cm/s for modern explosives.

In the case of the electron detonation (ED), the transformation of the substance behind the shock wave front is an endothermic process which results in the appropriate consumption of electromagnetic energy.

As distinct from explosive detonation, the specific energy of ED is a variable that depends on the rate at which electromagnetic energy is supplied to the energy release zone. Therefore, the ED rate can change within broad limits and reach values unachievable for explosive detonation.

Considering this feature of ED, two approaches must be used to describe it:

— a traditional approach for all types of detonation. According to the hydrodynamic theory, detonation is based on the simultaneous consideration of equations of state and the laws of conservation of mass flow, momentum and energy in the phase transition range.

— a new approach applicable only to an electrical or laser breakdown. This is based on the description of valence electron injection under conditions of shock compression.

Professor Vershinin proposed only considering his physical models of electron detonation as a first approximation. He was just as cautious in his evaluation of many other aspects of the electron-thermal and electron-detonation processes involved in the electrical breakdown of solid dielectrics. He suggested that further advances in the models would allow the versatility of the energy method proposed earlier to calculate volt-second characteristics of solid dielectrics to be explained [5] and lead to the development of universal methods for calculating high-voltage characteristics of discharge gaps with solid insulation, as well as methods for controlling the process.

The concluding section of the monograph [11] is perceived as a testament laying out the main lines for further experimental and theoretical research which is necessary to elevate the proposed models to the level of a theory. (He was aware of his incurable disease while writing the book.)

All the preceding is just part of the many-faceted scientific and engineering undertakings of Yuri Nikolayevich Vershinin. He supervised and approved investigations concerned with technical applications of superconductivity. They found that partial discharges play an important role in supercooled dielectrics used to insulate superconducting devices. The "betel" research branched into studies of physical-engineering fundamentals for the creation of modern grounding systems, which were developed by his followers. They became the first to formulate principles underlying the durability of underground systems of electrical installations. Many methods for testing high-voltage equipment—measurements of partial discharges, electron-optical flaw detection, etc.—were thus developed theoretically and technically.

Of course, the main legacy of Yuri Nikolayevich Vershinin is a vast and broad school of thought whose representatives, faithful to the maxims of their predecessor, work on the frontier of science and obtain interesting theoretical and practical results.

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