

Low-temperature electrical discharge through solid xenon

E.B. Gordon

Institute of Problems of Chemical Physics RAS, Chernogolovka 142432, Russia
E-mail: gordon.eb@gmail.com

V.I. Matyushenko and V.D. Sizov

Institute of Energy Problems of Chemical Physics RAS, Chernogolovka 142432, Russia

B.M. Smirnov

Joint Institute for High Temperatures RAS, Izhorskaya 13/19, Moscow 127412, Russia

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The uniform self-sustained electrical discharge through solid xenon has been realized and studied. The multiplication of electrons proceeds in the noble gas above the xenon crystal interface whereas a positive feedback is realized at the account of multiple exciton formation by excess electrons drifted through the crystal: molecular excitons emit VUV photons which knocked out secondary electrons from photosensitive cathode. The discharge was stimulated by short electrical spark along the sample axes. The discharge electrical properties as well as the spectra of solid xenon electroluminescence in UV and visible have been studied. Electric discharge in solid xenon was proved to be an effective source of UV radiation and a convenient tool to study the processes involving excitons and electrons in solid xenon at high pressures.

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1. Introduction

Electric discharge requires for its self-maintaining the reproduction of electrons and ions which go to electrodes [1]. In gases this reproduction results from atom ionization by electron impact. In contrast to gases where the energy distribution function of electrons has a long tail, in condensed heavy gases due to effective excitation of atoms the ionization of an atom occurred by impact with more fast electrons is absent. Nevertheless, the conditions of self-maintaining may be satisfied in solid inert gases if electrons are injected from outside where they are formed under the cathode bombardment by VUV photons which in turn are generated inside the condensed inert gas by these electrons drifted in an external electric field. This scheme was formulated [2,3] and then was shown to be realized in [4,5] for the solid xenon. The aim of present paper is to create the reproducible uniform electric discharge in solid xenon by brute force technique applicable

in principle for solid xenon at high pressures. The brief results of the studying such a discharge through solid xenon at ambient pressure are reported.

2. Peculiarities of electron drift in solid xenon

The mean free path of an excess electron in liquid and solid heavy rare gases amounts to many meters [6,7] and electron mobility exceeds that in a coin metal or in a gas of atmospheric pressure [8]. Meanwhile the absence of own free electrons makes possible there, unlike in metals and semiconductors, sustaining the electrical field inside a sample. Naturally the question appears [2,3], is it possible to organize an electrical discharge in the solid to excite and to ionize a matrix as it takes place in a gas? The answer depends first of all on the fact to what extent the unique high mobility of electron and its unique low elastic losses save themselves at high electron energy, because the growth of electron kinetic energy should result

in approaching the behavior of electron drifted in condensed media to that inherent to a gas [2,9].

Nevertheless it has been proved experimentally that even at moderate (around kVs per cm) field the drifted electrons can be accelerated up to energy of several eV being sufficient for the matrix electronic excitation [10,4,5]. However this fact itself does not facilitate the solution for the problem of electrical discharge creation. As the matter of fact the cross-section of electronic excitation as well as a cross-section of any nonelastic process has to be as high in a solid as in a gas. Thus at high densities typical for condensed matter the probability for drifting electron to excite a matrix just after the threshold overcoming is so large that at really accessible electric field the electron additional overheating up to the ionization threshold, i.e. 3 eV higher than the excitation threshold, is absolutely negligible. This fact is independent of the matrix temperature because the typical electron energy exceeds its thermal energy by two orders of magnitude. The probability of multi-step ionization is very low as well because the electronic excitation of a matrix immediately results in two-center trapped molecular-like exciton [11] formation which in turn decays emitting VUV photon, for short-living component the radiation time is as short as 30 ns even for Xe [12]. The feasibility of trapped exciton formation by electron impact in solid xenon has been experimentally proved previously [13,14].

The absence of ionization in the course of electron drift in condensed rare gases means the absence of electron multiplication being necessary for a discharge self-maintaining. Moreover, positive ions are practically motionless in a solid rare gas, so any electrical current through a sample should quickly dump due to the compensation of electric field by the accumulative space charge. Such a problem may be bypassed by using the electrical cell with photosensitive cathode [4]. Each electron creates many excitons during its drift through solid rare gas, every of them decaying with VUV photon emitting. This photon is able to cause the photoelectron effect striking a cathode; these additional electrons entering the matrix create the positive feedback that itself without ionization could provide the multiplication of number of electrons passed the sample and consequently the self-sustained current through it [5].

In practice, the following approach [4,5] is more convenient. In a three-electrode cell the xenon crystal is grown at the bottom, between the grid and anode. The gap between cathode and grid is filled by inert gas — xenon, argon or helium — at small pressure. In case of xenon the sample temperature has been kept equal to 115–132 K to have saturated vapor pressure in cathode-grid gap in the range 7–40 kPa; while using more light gases they put into cell at close pressure, the sample temperature was 77 K in the case. In electric field applied to the cathode-grid gap

the electrons emitted from cathode enhance their energy and then ionize gas forming the electron avalanche propagated from cathode to the grid with a speed above 10^7 cm/s. The electron number multiplication factor as high as 10^3 could be achieved in a regime of exponential growth, the Townsend discharge occurs at higher voltage. Passing a grid and then entering the xenon crystal the electrons drift there in voltage applied to grid-anode gap. As it has been shown in experiment the drifting electron passed the voltage of 1 kV induces emission of 20 VUV photons (172 nm) [5]. The geometrical probability for this photon to bombard the photosensitive cathode could be estimate as 20% whereas the photoelectron emission yield for zinc at $\lambda = 172$ nm is $5 \cdot 10^{-4}$ [15]. These estimates demonstrate the possibility to achieve the conditions of chain-branched electron multiplication being the analog of self-sustaining electrical discharge regime. Unlike common discharge the charge carrier multiplication takes place in a gas whereas the positive feedback, being necessary for self-sustaining operation, occurs in a solid at the account of molecular-like exciton electroluminescence caused photoelectrical effect on the cathode.

In principle self-maintaining electrical current in xenon could be realized as it was proposed in Ref. 2 without any electron avalanche in a gas. However when metallic cathode contacts directly with solid xenon the effect of so-called back diffusion appears diminishing by orders of magnitude the probability for photoelectron to enter the crystal, CsI cathode is lucky exclusion because the probability of electron capturing by liquid xenon has shown to be as high as 0.1 there [16].

In experiment with three-electrode cell we really observed the transition to self-sustaining discharge (generation) that is characterized by appearance and subsequent growth of regenerative peak in electron current, with its maximum realized, as it follows from general considerations, at the moment of positive feedback termination [4,5]; the primary electrons were created by exposing the zinc cathode to short pulse of 4th harmonics of Nd:YAG laser irradiation (266 nm). The positive feedback duration was naturally equal to the time of excess electron drift through the xenon crystal. That time was known with good accuracy because in the field range 10^2 – 10^5 V/cm the electron drift velocity in condensed xenon did not depends on the field strength and was equal to $2 \cdot 10^5$ cm/s [8].

Regretfully, as in any experiment where electrons move through solid dielectrics, there is a limit for the total charge flowing through the sample that stops the current through the sample. That is due to molecular admixtures that capture electrons and create a motionless volume charge. Any purification method, including the effective electro-spark technique [17] we used, can not diminish the electronegative impurity (oxygen first of all) content below 0.2 ppb, that corresponds to molecular density in a

solid of $6 \cdot 10^{12} \text{ cm}^{-3}$. All these molecular traps capture the electrons provided the current exists enough long. In our geometry the corresponding charge density is sufficient to compensate the fields with the strength exceeding 100 kV/cm. That is why a scientist used to work with as low current as possible within the time when the current is still not terminated. Then, in order to continue the experiment one should remelt the sample. In our conditions the limiting time of «discharge» existence was only tens of seconds.

It is turned out however that provided all resistors restricting the current in electrical circuit were removed the compensation of electric field by accumulating space charge did not exist anymore and the discharge initially triggered by laser pulse may exist for ever. Such a behavior we explained hypothetically [4] by trapped electron blowout under impact with fast drifting electron. The electron affinity to molecular oxygen is only 0.43 eV, so the cross-section of the electron detrapping by impact of free electron having sufficient energy should be enough high [18]. Thus starting from some density of excess electrons the steady concentration of motionless negative charges (defined by equilibrium between free electron trapping to impurity and negative ion decomposition by the impact with free electron) may become to be less than that compensating the voltage which induces a drift.

This work is devoted to testing that hypothesis, to realization of steady bulk «discharge» in solid xenon, as well as to studying this phenomenon being peculiar and attractive for the applications, especially for revealing the xenon matrix transformation at very high pressure. The problem of the discharge initiation is to be cardinal because due to quadratic dependence of the detrapping rate on free electron density a steady discharge can not be achieved spontaneously.

Though the principal ability for excess electron to drift in nonpolar solid as it does it in a gas is obvious, the feasibility for an electron to acquire the energy sufficient for the new charge producing in reasonable electric field is the specificity of a condensed matter. In dense gas such a process will be simply impossible (as the experiments have shown [19] the discharge threshold starting from gas pressure of 100 bar rises to the electric field strength practically unattainable due to breakdown occurrence). Quite natural and important from viewpoint of possible application at high and ultrahigh pressure is the question what should happen at atomic densities higher than those characteristic for solid and liquid states at normal conditions. In other words, one should distinguish whether high mobility of excess electron is a consequence of accidental coincidence of the density of condensed heavy rare gases at normal conditions — about $3 \cdot 10^{22} \text{ cm}^{-3}$ — with the density when the compensation of an electron attraction and repulsion to atomic system provides the weakness of its interaction with media [20], or that high mobil-

ity has to last in wide range of densities, and consequently pressures. Of course, high pressures should induce the other effects as well and they will be analyzed in this work too.

3. Experimental setup

The design of the technique built up in IPCP RAS is shown in Fig. 1; it is close to that described in Ref. 4. Only the materials and tools destined for ultrahigh vacuum operation have been used in assembly. All tubes were from stainless steel, the Varian flanges and copper gaskets, as well as Swagelok ferrules, pipes and nuts were used for connectors. In construction of both discharge cell and xenon purification chamber any plastics, glues, and even silver soldering were avoided, last due to impossibility to remove the traces of flux; only indium (for sealing), sapphire, glass, Kovar, and Macor ceramics were applied as materials. Whole vacuum system could be degassed by heating up to 200°C. The Varian Turbo-V70 turbomolecular pump supported by Varian SH-100 scroll pump were used, the stainless steel gas receivers had special fingers for xenon condensation by liquid nitrogen. Pressure was measured by the modification of Barocell pressure gauge compatible with high vacuum.

Necessary efficiency of xenon purification from electronegative impurities — about 10^{-10} — can not be kept for a long time in separate cylinder. Thus the purification system periodically retrieved the necessary purity was an incorporated part of setup. The electrospark method of xenon purification has been used as previously [4]. The titanium blade-shaped ring served as cathode and steel cylinder was used as anode, interelectrode distance was 0.2 mm. Before operation the purification chamber has been submerged to the liquid ethyl alcohol perma-

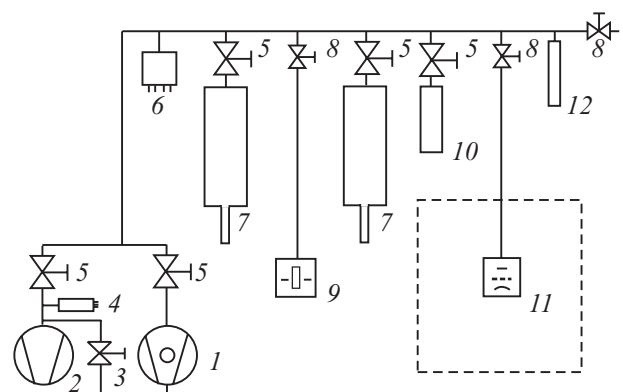


Fig. 1. Setup scheme: turbomolecular pump (1); scroll pump (2); vacuum valve (3); Pirani pressure gauge (4); ultrahigh vacuum valves (5); Barocell pressure gauge (6); stainless steel cylinders with finger (7); high vacuum valves (8); purification chamber (9); stainless steel cylinder (10); experimental cell located inside of cryostat (11).

nently cooled down to porridge-like consistence by adding liquid nitrogen. Liquid xenon interface was 1 cm higher than cathode level. The homemade high voltage power supply had manipulated output from 1 to 10 kV. Because the frequency of 75 kHz has been rectified there the output capacitor intended for smoothing the signal had a low capacity and as a result the output energy was insufficient for the spark development — at high anode-cathode voltage an electric arc simply appeared inside liquid Xe. With the additional 0.1 mF outlet capacitor one or two sparks exist, moving around the interelectrode gap as metal sputtered, starting from some voltage applied — at 1.5 kV for nonpurified xenon and at 8 kV at the end of procedure. The spark current has been limited by powerful 1 M Ω resistor. The cavitation accompanied the electrical breakdown provided intensive intermixing of liquid xenon supplying the spark region with new portion of a liquid. Several hours of such a procedure were sufficient to diminish the contamination of Xe down to 0.2 ppb in a few cc of liquid.

Liquid nitrogen optical cryostat has been designed especially for this study in the Institute of Solid State Physics RAS. It possesses 4 arrays of sapphire optical windows suitable as for UV range where excitonic emission takes place as in visible and near IR ranges. The complexity of perfect xenon crystal growing consists of small, less than 2 K, gap between the temperatures of Xe melting and boiling. Due to large volume of the sample and consequently large heat releases under gas xenon condensation and then its solidification, the common technique of temperature stabilization with feedback was inapplicable. The system of stabilization we chosen acts as follow. The homemade controller kept the excess pressure of vapor in liquid nitrogen jacket constant and equal to 0.2 bar. The main bath of the cryostat where the experimental cell was situated has been connected to ambient air through a needle-valve controlled the rate of gas outflow and such a way the supply of liquid nitrogen from the jacket to main bath through a capillary, the necessary flow has been determined experimentally. The temperature of the cell was measured by copper-constantan thermocouple. At the moment when necessary amount of liquid xenon has been condensed to the cell it was sealed from the supply system by the valve and the outflow controlled by needle valve was strongly diminished (to compensate the sharp cessation of heat release at the end of condensation). When in a few minutes the temperature reached the Xe triple point $T = 161$ K the needle-valve has been closed at all, the crystallization proceeded isothermally and frontally from the down to the top during about 20 min. After the crystallization completion the cooling rate was quickly enhanced and after the temperature becomes to be 77 K whole cryostat bath was filled by liquid nitrogen. The quality of the crystals such grown was better then previously [4].

In this work the new design of three-electrode experimental cell has been used, the photo is presented in Fig. 2. Its body was the sapphire tube 1 with 28 mm inner diameter gripped through indium sealing between two steel flanges 2 and 3, the possibility of optical observation both in UV, visible and IR ranges has been achieved in such a way. To compensate mechanical tension appeared under temperature changes and being large enough due to the diversity of materials applied in construction, the flanges were pressed to sapphire tube through flat spring 4 as it has been done in the cell meant for work with solid helium [21].

The bottom flange 2 served as anode and its working surface 6 was uplifted on 3 mm to avoid the electrical breakdown from indium spew, squeezed out inside the cell under sealing, to grid 8 along the side surface of a crystal. Two 40 μ m tungsten wires were installed at the center of anode; they rose on 0.5 mm above its surface. Their task was to give rise powerful spark initiated the main discharge.

The zinc cathode 10 mm in diameter was attached to upper flange. The distance between cathode and grid made of stainless steel mesh with 60% geometrical transparency was 2 mm and their electrical insulation has been attained by figured gasket made of Macor ceramics. By changing the length of cathode holders the distance

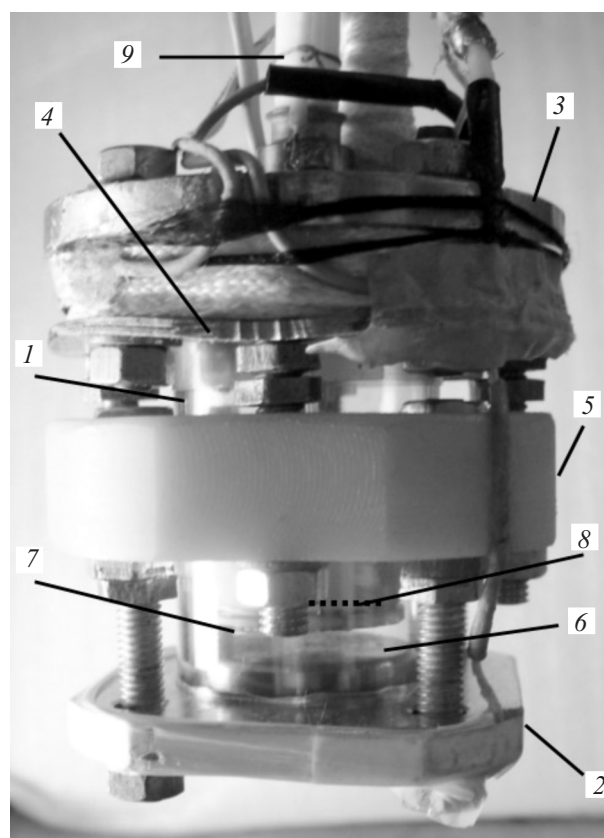


Fig. 2. Experimental cell: sapphire tube (1); bottom flange (2); upper flange (3); stainless steel flat spring for thermal expansion compensation (4); Caprolan insulator (5); anode surface (6); mesh grid (7); the position of zinc cathode inside of Macor gasket (8); high-voltage feedthrough (9).

between grid and anode determined the maximal sample thickness could be changed from 2 to 4 mm. The cell was provided with electrical heater rolled around upper flange and with thermocouple.

Unless a discharge was terminated by space charge captured by the impurities presented inside a sample, its power was so large that it could melt whole crystal during few seconds. For this reason the 430 pF capacitor was used as voltage supply. It was charged by the power unit through 110 kΩ resistor; the discharge current has been restricted by 1 kΩ resistance. The same scheme was used for grid-anode feeding, 0.1 μF capacitor was charged through 10 MΩ resistor in the case. Owing to this the discharge represents the sequence of short pulses; the repetition rate dependent on power unit voltage was usually chosen about 1 Hz.

4. Experimental results

The different regimes of electric discharge through solid xenon are illustrated by Fig. 3. The visible glowing was extremely intensive — all photos were made at daylight and background looks like black in the presence of discharge only by contrast. The shape of xenon sample is shown in upper photo. Only spark breakdown takes place at small voltage U applied to gas gap, as it is seen from the next photo. The observation through the mutually perpen-

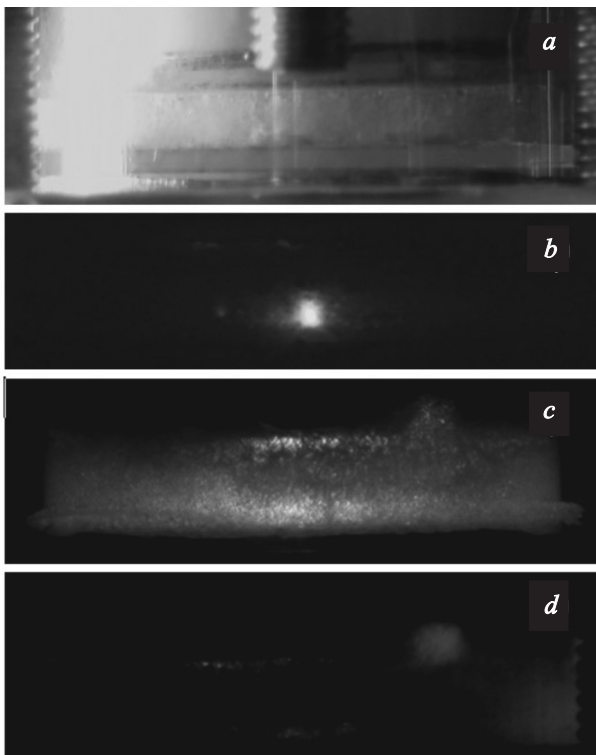


Fig. 3. The photos of different regimes of electron current through solid xenon at constant grid-anode voltage, $U_{ga} = 2.4$ kV, and different cathode-grid voltages, U_{cg} : a) $U_{cg} = 0$ (no current); b) $U_{cg} < 100$ V (only spark); c) 100 V $< U_{cg} < 200$ V (uniform discharge); d) and $U_{cg} > 200$ V (weak glow).

dicular windows manifests the spark to be just at axes of the cell and crystal. The temporal profile of the current in cathode-grid gap at such a condition is shown in Fig. 4, and the «spark» duration equal to 300 ns together with its high brightness and comparably large for a spark radius indicate that is not simple breakdown; namely the noticeable part of its trace an electron does not moved in a crack but drifts through a crystal bulk nearby.

Beginning from some threshold voltage U , extremely bright uniform glow sharply appears in whole sample volume, the pulse repetition rate does not change at this moment. The pattern of this discharge shown at Fig. 3,c is the same being observed through the windows from all four sides of the cell, no extra intensity was found both at the center there the spark has been before and at the edges of crystal, last is the evidence for the absence of specific role of sample surface in emission. The durations of both light and current pulses were almost two orders of magnitude more long than those in the regime of spark breakdown (look at correspondent oscillogram in Fig. 4). The charge re-establishment time for the feeding capacitor in cathode-grid circuit is rather short $\tau_c = CR = 0.43 \cdot 10^{-9} \text{ F} \times 1.1 \cdot 10^4 \Omega = 50 \mu\text{s}$; thus the observed discharge repetition rate (about 1 Hz) is definitely controlled by the charge of capacitor in the grid-anode circuit, where re-establishment time really is $\tau_c = CR = 1 \cdot 10^{-7} \text{ F} \times 1 \cdot 10^7 \Omega = 1 \text{ s}$. According to voltmeter readings the capacitor is loosing practically all its charge to the end of every discharge pulse; it means that the charge flowed through the grid-anode gap filled up with solid xenon $q = CU = 1 \cdot 10^{-7} \text{ F} \times 2.4 \cdot 10^3 \text{ V} = 2.4 \cdot 10^{-4} \text{ C}$ is much more than that flowing through the cathode-grid gap filled up with a gas $q = CU = 0.43 \cdot 10^{-9} \text{ F} \times 1 \cdot 10^2 \text{ V} = 4.3 \cdot 10^{-6} \text{ C}$. In other words, the additional charge carriers — electrons — in amount being 50 times more than that in a gas gap are formed in the grid-anode gap. Since only electrons es-

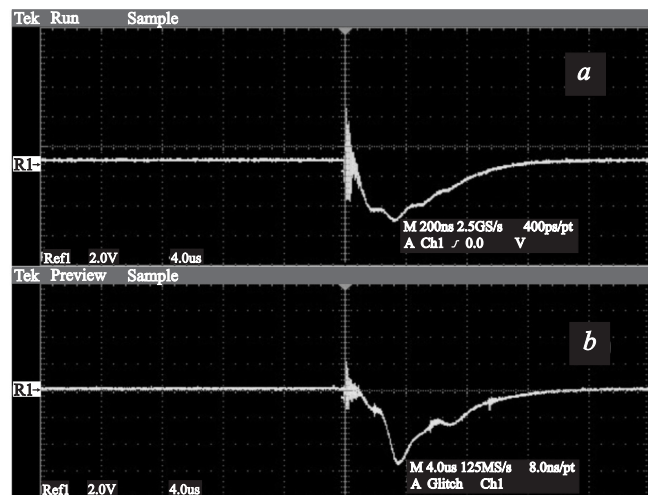


Fig. 4. Oscillograms of visible emission intensities in a) «spark» regime, time scale 0.2 μs/div, and b) discharge regime, time scale 4 μs/div.

caping a cathode are then multiplied in a gas the effect hardly could be attributed to less efficient photoelectric effect on the grid surface. Most likely the reason is the additional electron multiplication in the narrow gap between the grid and upper surface of crystal: taking into account the high xenon dielectric constant equal to 1.8 the electric field there is 40 times more than in cathode-grid gap. For achieving the additional multiplication factor in electron avalanche equal to 50 it is sufficient to have a gas slit between a grid and upper crystal face only 0.10–0.15 mm.

Rather low electrical resistance of a crystal follows from discharge pulse parameters observed — since the discharge duration of 4 μs is sufficient for 0.1 μF capacitor depletion, the impedance should be less than 40 Ω . In accordance with that estimate the introduction of 1.3 k Ω resistor into discharge circuit entirely kills the discharge through solid xenon. Meantime the gas gap impedance was not less than 15 k Ω . The analysis of light emission pulse presented in Fig. 4 leads to the interesting conclusion: there are few successive electrical breakdowns of solid sample. The moments of sparks appearance are seen due to high-frequency noise they induce at the background of a signal detected by photodiode. Every spark gives birth to its own electron avalanche in a gas gap and then to its own «discharge» through solid xenon. Every discharge such induced represents the pulse having the maximum at the electron time-of-drift through the sample being equal in our case to 2 μs . Such a behavior is typical for any generator: the additional pulsed excitation of a generator already working in a steady regime causes a perturbation existed during the time of positive feedback action. The same shape had the regenerative peak of discharge current we have observed in vicinity of the threshold of self-sustained discharge through solid xenon [4,5]. Such effects are quite naturally more significant near the vertical axes of a sample where initial breakdown takes place. Thus they are less indicative in current signal, that, contrary to emission collected by lens from the central part of a sample, represent total electron current through a sample.

The most convincing argument in favor of such interpretation of the experimental data is the discharge behavior under further growth of voltage applied to cathode-grid gas gap. Both current and light emission are practically invariable while voltage grows from 100 to 200 V, but then the crystal glowing intensity falls down step-wisely and becomes comparable with emission of gas discharge in cathode-grid gap (see Fig. 3,*d*). Due to the small discharge current at that stage it can be feed continuously through the 10 M Ω resistor — the glowing observed becomes continuous-wave indeed. Such a behavior saves at further voltage growth above 200 V. The threshold voltage values presented above are dependent of course on the sample thickness.

The unusual effect of discharge depression whereas the voltage applied to gas gap and consequently the factor of electron multiplication in avalanche both grow can be rationalized as follows. Beginning from cathode-grid gap voltage 200 V the continuous-wave discharge through gas gap appeared — it was observed at close voltage in absence of grid-anode voltage as well. It causes effective permanent bombardment of a crystal by electron escaping gas discharge area. Such pre-ionization of a crystal becomes to be high enough for suppressing the spark development. As a result, only weak discharge, controlled by the space charge of impurity negative ions, took place.

Beside VUV luminescence from excitons the intensive emission in UV and visible has been registered from uniform discharge through solid xenon. The overview spectrum is presented in Fig. 5. The main lines there belong to xenon, they are slightly broadened and (about 0.4 nm) shifted to the blue from their gas phase positions. It is very interesting that we observed all lines of ions Xe^+ usually present in gas xenon discharge but no line of Xe atom has been registered including these possessed high intensity in both high and low pressure xenon gas discharges [22,23]. As we already mentioned, the direct ionization of a matrix is impossible in our conditions, just preliminarily excited species could be the precursors of

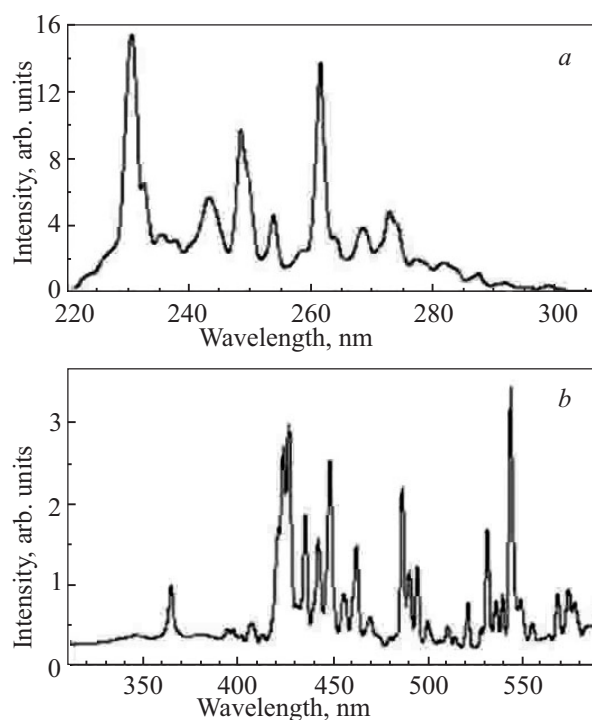


Fig. 5. Overall spectra of solid xenon in visible (*a*) and UV (*b*) regions. No correction for spectral sensitivity of photomultipliers has been made. Xe crystal was kept in equilibrium with its vapor at 132 K, thus the cathode-grid gap was filled by xenon with pressure around 4.5 kPa. The width of individual lines registered at low monochromator scanning rate was 0.4 nm.

ions. Since only excited species are molecular-like excitons the process



should be rather effective under hot electron impact or VUV quantum absorption. Note that unlike gas phase where negative ions Xe^- do not exist, the excess electron potential energy is negative in solid xenon lattice.

Another peculiarity of solid xenon is the narrowness of the exciton emission band: while in a gas and in a liquid the intensive luminescence arises already at 200 nm we see no traces of emission at 190 nm.

Extra spectral lines and continuums presented in spectra of discharge in solid xenon may belong to impurities. Though they regretfully related to unknown centers, the high intensity of emission from trace species with relative content about 10^{-10} is good evidence for high probability of electroluminescence connected with the fact that real path of drifting electron in a sample is 10^3 times longer than the sample thickness [4].

That is especially interesting for spectroscopic and other physical and chemical applications that the method of organization of electric discharge through solid xenon is the brute force technique: no external factors are necessary for realization. One should only prepare the sample and apply the electric field of sufficient strength to it. If so the discharge can be developed without any optical access to a sample, in particular in the experiments with extra high pressure and in blasting operations [24].

Such a way the universal approach has been developed allowing, on the one hand, introducing excess electrons to solid xenon and, on the other hand, studying the interactions of hot electrons with practically any molecules isolated in inert matrix. The temperature can be arbitrary low provided the helium will be used as the gas in cathode-grid gap.

5. About the discharge through solid Xe at high and ultrahigh pressures

The method under consideration may be applied in principle to high-pressure studies of the behavior of excess electrons in solid xenon. As it was shown in Ref. 25, the current of excess electrons proceeds in a space along the tubes whose axes are Voronoi–Delone channels. This is additional to the classical description of the electron behavior in metals on the basis of the Fermi surfaces and exhibits that the metal conductivity is not a result of the crystal structure of metals only. That is of obvious interest to investigate the excess electron current at pressure being high enough to modify electron potential inside a solid. However, even the very feasibility to organize a discharge at high pressure is not quite clear and both theoretical and technical analysis is required.

Thus the simplest approach, applicable however only for blasting experiments, is the exposition to shock-wave compression of xenon crystal with preliminarily sustained electrical discharge. Because the duration of a discharge in a sample of 1 cm thickness is about 5 μs one has a time for pressing. The presence in a sample of excess electrons makes it possible to study the electron mobility far below the pressures provided effective ionization of a matrix.

The realization of the method in the condition of static compression looks much more problematic. First of all in the design of an experimental cell the gas gap above the crystal should be removed because the discharge through high pressure gas is impossible. However the experience of present experimental work shows that this difficulty may be bypassed by using two-electrode cell with CsI cathode. The effect of back diffusion is absent here, and the absence of electron multiplication in gas avalanche will be compensated by higher photocathode efficiency and removing the screening of electroluminescence by mesh grid.

In principle beginning from high enough pressure the chemical potential of excess electrons in solid rare gas becomes positive, so thermal electron could not enter the sample then. However our estimates show that it is important only for more light rare gases, for xenon such a pressure is about 130–150 GPa. Such a way this effect does not prevent a static operation, in particular in a frame of technique based on diamond anvils [26].

For the studies at static pressure the crucial question is the possibility for an excess electron to be accelerated in a solid at high pressure, the exciton and molecular ion structures and energies are of great importance in this case.

We now examine briefly the properties of compressed xenon which should be analyzed in future work. At very high pressures and consequently at very small distances between nearest neighbors, the electron band of valence electrons intersects the boundary of continuous spectrum, and then xenon becomes a metal. According to experimental study [27,28], the dielectric-metal transition for xenon occurs at the pressure of 130–140 GPa. But considerably below this pressure the gap between the electron valence band and the boundary of continuous spectrum decreases to form a broad dielectric–semiconductor–metal transition.

The study of intermediate semiconductor state of xenon would give a more profound understanding the dielectric–metal transition. But in practice the conductivity in the semiconductor regime should be entirely defined by electronegative impurities and not by own matrix ionization. Only a deep ($<10^{-7}\%$) xenon purification together with injection excess electrons into the matter would remove this trouble.

In principle, two types of the electron excitation, atomic and molecular, are possible in condensed inert

gases at moderate pressures. In reality, only molecular exciton emission is observable in solid xenon with a spectral band position close to that of Xe_2^* excimer band in a gas. Meantime, the molecular spectral band should disappear at enough high pressure because small distances between the excited atom nearest neighbors exclude existence of its bound state with one atom. The corresponding pressure and the character of exciton band distortion and decay are of obvious interest.

We now enumerate the effects appeared in solid xenon as the pressure increases and revealed themselves as the changes in excess electrons mobility and excitonic luminescence characteristics.

First of these is a drop of the mobility of excess electrons when a pressure increases above atmospheric one at which the reduced mobility of excess electrons in solid xenon exceeds by three-four orders of magnitude that in gases of the same pressure [19]. That high electron mobility can be explained by existence of Voronoi–Delone channels between xenon atoms, where a slow electron propagate [20]; these regions will disappear at high pressures resulting in significant decrease of slow electrons mobility.

The next effect consists in strong distortion of excitonic luminescence band shape. At atmospheric pressure molecular-like exciton emission is close to that of Xe_2^* excimer molecule in a gas due to large difference between interatomic distance in two-center exciton and that in a matrix. But a pressure increase leads to a decrease in the distance between nearest neighbors of solid xenon, and at certain pressure the molecular-like spectrum will be replaced by the atomic-like one. All these effects are expected already in the kbar pressure range.

At higher pressure the effect of diminishing the energy necessary for atomic ionization in a matrix becomes important. That is the consequence of two effects. On the one hand, the system electronic ground state goes up due to exchange interaction between valence electrons, and on the other hand, the level of ionic state goes down. But last effect is of another nature than that for the ground state. Indeed, the electron term of the ionized state in average does not change but splits into many levels transformed to expanded band. Both effects lower the ionization energy and so-called «ionization by pressure» proceeds of course via lower edge of ionization band. Of course, excitonic emission should disappear at that pressure as a result, and then the ionization of the matrix by excess electrons accelerated in electric field may proceed. This effect can display the threshold behavior and in this case it could be interpreted as insulator–semiconductor phase transition.

Beginning from such a pressure together with the current of excess electrons the conductivity of pure matrix should take place, especially in blasting experiments where the temperature of compressed matter is high

enough and large amounts of intrinsic free electrons appear at pressures significantly lower than those corresponded to metallization, i.e. forbidden band disappearance. The mobility of the electrons may be at the same time still rather low, and only at high inner ionicity the character of bonds should vary from van der Waals binding to metallic one. New ordering such appeared will restore high mobility up to that inherent to a metal.

Probably in the same range of pressure the electron will loose its ability to penetrate inside solid xenon from gas phase because the electric potential inside solid xenon for a slow electron becomes higher than that outside it.

6. Conclusion

The experimental approach just elaborated allows the creation of stable uniform electrical discharge inside solid xenon. High energy electrons make it possible to excite the xenon matrix as well as the impurities stabilized inside solid xenon and to cause their chemical reactions in inert matrix at arbitrary low temperature. The method luckily can be realized at high and ultrahigh pressure as well. The feasibility of introducing large amounts of excess electron into compressed solid xenon assures the experimental observation of several pronounced effects. Their characteristics will be reliable base for detailed theoretical analysis and, that is especially important, for understanding the matter transformation at high pressure at all. The design of the technique allowing the excess electron introducing into solid xenon being compatible with conditions of blasting experiment is now in progress.

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