1. Fatiha GHALEB[1], 2. Bruno CAILLER[2], 3. Ahmed BELASRI[1], and 4. Soumia BENDELLA[1]

Laboratoire de Physique des Plasmas Matériaux Conducteurs et leurs Applications, Université des Sciences et de la Technologie Mohamed Boudiaf USTOMB, El M'Naour B.P.1505 Oran, Algeria (1), Laboratoire Diagnostic des Plasmas Hors Equilibre DPHE, Institut national Universitaire Champollion, Albi, France (2)
ORCID: 1. 0000-0002-1535-4114

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Experimental study of the breakdown process in planilum dielectric lamp

***Abstract**. Applying an electric field to a gas environment can result in complete or partial breakdown, resulting in a conductive medium referred to as plasma, made up of electrons and free ions. Electrical breakdown of plasma is run with a high pressure gas, for which the breakdown voltage reduction can be accomplished by mixing a percentage of xenon in the neon. The UV light emitted by xenon plasma is converted into visible light. Several factors such as electric field strength, gas type and gas pressure and geometry influences breakdown. This measurement is based on these factors as electrical breakdown parameters. Our work is an experimental measurement of breakdown voltage according to the product of the electrode spacing and the pressure in a lamp that consists of two planilux glass plates designated by PLX. These two barriers are filled with a xenon-neon gas mixture. The results obtained show some factors that affect the Paschen curve such as the xenon percentage in xenon-neon gas mixture as well as the parametric effect of the geometry which we use to increase the luminous efficiency and to reduce the breakdown voltage of this Planilum dielectric lamp.*

***Streszczenie.** Przyłożenie pola elektrycznego do środowiska gazowego może spowodować całkowite lub częściowe przebicie, w wyniku czego powstanie ośrodek przewodzący zwany plazmą, składający się z elektronów i wolnych jonów. Przebicie elektryczne plazmy odbywa się za pomocą gazu pod wysokim ciśnieniem, dla którego zmniejszenie napięcia przebicia można osiągnąć poprzez zmieszanie procentu ksenonu z neonem. Światło UV emitowane przez plazmę ksenonową jest zamieniane na światło widzialne. Na przebicie wpływa kilka czynników, takich jak natężenie pola elektrycznego, rodzaj gazu oraz ciśnienie i geometria gazu. Pomiar ten opiera się na tych czynnikach, takich jak parametry przebicia elektrycznego. Nasza praca polega na doświadczalnym pomiarze napięcia przebicia w zależności od iloczynu odstępu elektrod i ciśnienia w lampie składającej się z dwóch szklanych płytek planilux oznaczonych przez PLX. Te dwie bariery są wypełnione mieszaniną gazów ksenonowo-neonowych. Otrzymane wyniki wskazują na pewne czynniki wpływające na krzywą Paschena, takie jak procentowa zawartość ksenonu w mieszaninie gazów ksenonowo-neonowych oraz efekt parametryczny geometrii, którą stosujemy w celu zwiększenia wydajności świetlnej i zmniejszenia napięcia przebicia tej dielektrycznej lampy Planilum **(Badania eksperymentalne procesu rozpadu w lampie dielektrycznej planilum)**.*

Keywords: Planilum lamp, breakdown voltage, dielectric barrier, Xe-Ne gases.
Słowa kluczowe: Lampa planilum, napięcie przebicia, bariera dielektryczna, gazy Xe-Ne.

Introduction

The electrical breakdown of a gas can be defined as the transition from an insulating state to a conductive one; this phenomenon is characterized by a minimum voltage called the breakdown voltage V_b [1, 2]. This voltage is described by the Paschen's law which explains this transition in electrical discharges. Paschen in 1889 performed experiments, studying the minimum potential difference that was needed to create a spark between two electrodes in a glass tube. He found that this voltage depended on the type of gas, the pressure in the tube, and the separation distance of the electrodes *d* [3–6]. The breakdown voltage is obviously a very important parameter which must be reduced in order to avoid excessive consumption of energy and also to simplify the control electronics [7]. Paschen curve describes the gaseous breakdown voltage as a function of the reduced variable of the pressure-gap spacing product [8]. Typically, breakdown voltage generally forms a fairly smooth curve with a minimum breakdown voltage at a specific *P.d* [9, 10]. The breakdown voltage represents a balance between the number of electrons lost by the diffusion and the number of secondary electrons created by the cathode or by the secondary emission coefficient, for that it is necessary to try to reduce this voltage [11, 12]. This can be carried out while exploiting the parameters (product pressure-distance, composition of gas mixture, electronic multiplication) [13–15]. The curve to be determined which gives the breakdown voltage according to the product pressure-distances (*P.d*) is called the Paschen curve [16, 17].

The experimental measurement consists of observing the behavior of the plasma medium [18] that we wish to study, for this an experimental study has been done to provide much information on reducing the breakdown voltage by experimental parameters, and increasing the effective yield of the secondary electrons leaving the cathode by ion bombardment, which is defined as the ratio of the electron current to the ionic current at the cathode, and implicitly represents the contribution of the species mentioned in this work above. In this work, the Paschen curve can be measured directly from an experiment performed with a PLX lamp, at different configurations, as well as different noble gas mixtures.

Experimental details

Our geometry uses a discharge with dielectric barriers to generate VUV photons which will excite a layer of phosphor deposited on the internal faces of these barriers. The phosphor surface will therefore behave like a surface emitting visible light. The dielectric barriers are transparent. The Planilum lamp uses the classic structure of a dielectric barrier discharge [19-20]. Two glass plates of the “Planilux” type (standard glass manufactured according to the so-called “float” process and designated by PLX [21, 22]. On the internal faces of the two plates, a mixture of phosphor is deposited in standard configuration by screen printing. However, the thickness of the deposit is different for each face. The lamp used in the experiment is characterized by a square power supply at a pressure which varies from 150 to 1 mbar, consisting of two "Planilux" glass plates and designated "PLX" and measures 4 mm thick. These plates are the dielectric barriers. A space of 3 mm between the dielectric barriers filled with a mixture of rare gases is maintained over their entire surface which is equal to 30×30 cm^2. On the dielectric surface, glass beads with a diameter of 2 mm are distributed evenly over the entire dielectric surface of 30 mm at a constant distance between each ball, to maintain a fixed distance between the two glass plates (barriers).

Two transparent copper electrodes are glued on each side of the dielectric barrier, in plane geometry (Fig. 1a), as well as coplanar geometry (Fig. 1b), the two electrodes are glued on a single barrier. One of the electrodes of these two geometries is connected to the 0V potential (ground) and the other one is connected to the voltage delivered by the square supply.

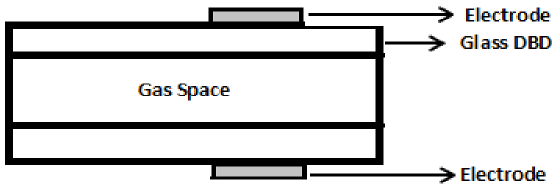

Fig.1a. Structure of the lamp DBD, plane geometry.

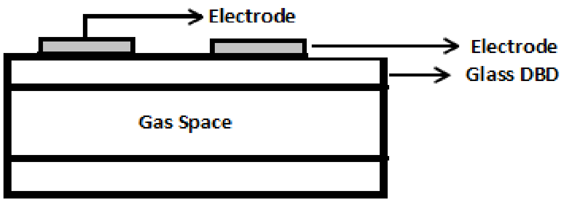

Fig.1b. Structure of the lamp DBD, coplanar geometry.

Our Planilux lamp is used as a reference for the various studies. For this, a square signal power supply was used to characterize its operating regime. This power supply can deliver a voltage of up to 1000 V.

Results and discussion

Comparison between two different geometries

In this work, we used two different geometries composed of two copper electrodes; we changed the interelectrode distance or the gas space in coplanar geometry from 1 mm to 80 mm for different pressures, which vary from 40 to 120 torr, for a mixture of 50% xenon in the neon (Fig. 2), and Xe10%-Ne in (Fig. 3). We observed a difference attaining 150 V between the two different geometries, in 50% xenon mixture in the neon. On the other hand, in the case of mixing Xe10%-Ne, the difference was rather small, less than 100 V. If we compare the two figures (Figs. 2 and 3), the breakdown voltage increases with increasing percentage of xenon; this is due to the use of neon as a parent gas. This latter reduces the breakdown voltage, it also has a large secondary emission coefficient; besides, these ions are more effective than that of xenon [23, 24]. Breakdown voltageis very high in mixture when increasing the percentage of xenon. This makes the gas have a low secondary emission coefficient.

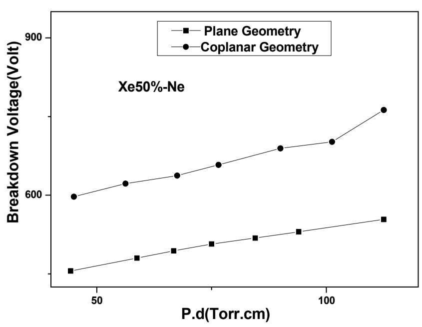

Fig.2. Comparison of the breakdown voltage between coplanar and plane geometry's for Xe50%-Ne gas mixture.

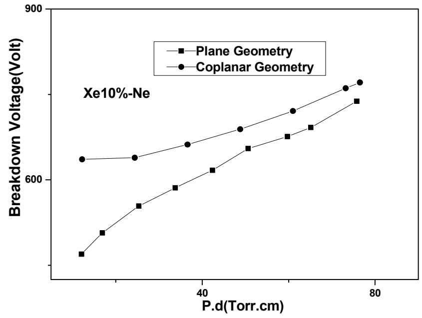

Fig.3. Comparison the breakdown voltage of the two geometries (coplanar and plane), in mixture Xe10%-Ne gas mixture.

Parametric measurement

In this part, we highlighted several parameters on the role played by the surface effect of the electrodes, as well as the geometry of the cell for the two mixtures, 50% xenon-neon and Xe10% -Ne, by varying the interelectrode distance and the gas pressure.

Effect of frequency

Three frequencies were taken into account: 20, 30 and 50 kHz for a mixture of 50% of xenon in neon.

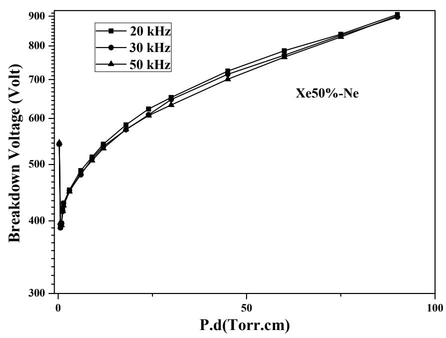

Fig.4. Variation of the breakdown voltage as a function of the pressure-distance product, and for three successive frequencies 20, 30 and 50 kHz, in a mixture of Xe50% -Ne.

In Fig. 4, we have drawn the breakdown voltage as a function of the pressure-distance product, for a mixture of 50% xenon in neon. We considered three different frequencies 20, 30, and 50 kHz. This allowed us to highlight the influence of the frequency on the breakdown voltage. We noticed that the three curves had the same Paschen minimum which is equal to 390 V and it is shifted towards the weak pressure-distance products. A fast increasing was seen in this voltage for the three curves, to reach a value of breakdown voltage V_b = 900 V.

Effect of the electrode surface area

In this part, we have chosen to put three electrode surfaces area above the dielectric barriers in a plane geometry which has a low breakdown voltage. We took three following surfaces (s_1=5×5 cm^2, s_2=1×1 cm^2, and s_3=3×3 cm^2). Fig. 5 presents the breakdown voltage for a percentage of 50% of xenon in the mixture, and Fig. 6 indicates the same parameter for a mixture of Xe10% -Ne, in order to see the influence of these surfaces (s_1, s_2, s_3) on the breakdown voltage in the planilux lamp for a dielectric barrier discharge.

In the two figures (Figs. 5 and 6), we see very clearly that the surface of ion bombardment of the electrodes plays a very important role. When the surface is increased, the breakdown voltage decreased due to the plasma volume and electron density increasing's.

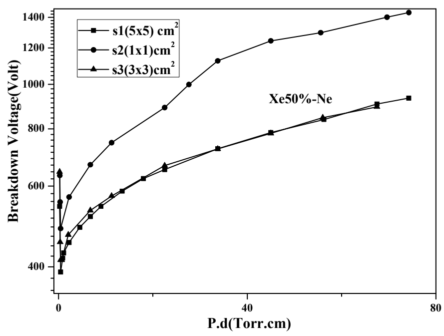

Fig.5. Variation of the breakdown voltage curve for three electrode surface areas, used in Xe50%-Ne gas mixture (plane geometry).

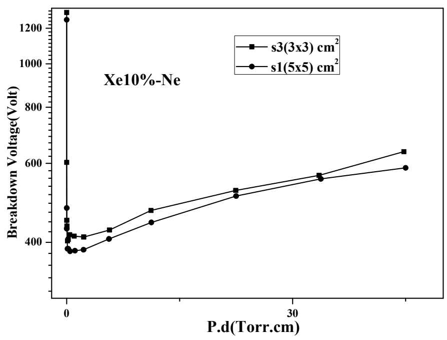

Fig.6. Variation of the breakdown voltage curve for two electrode surface areas, used in Xe10%-Ne gas mixture (plane geometry).

Effect of xenon content in neon

We tried to measure the breakdown voltage as a function of the product pressure-distance for the two mixtures used in our work to get an idea on the increase of the percentage of xenon in the mixture of xenon-neon. The results are represented in the following:

In both Figs.7 and 8, we compared two percentages Xe50%-Ne and 10% of xenon in the gas mixture for a plane and a coplanar geometry's, successively, and for an electrode surface of 5×5 cm^2. We noticed that the breakdown voltage is lower for the mixture of Xe10% -Ne compared to the mixture of Xe50% -Ne, which is confirmed by experimental [20, 25, 26] and theoretical [2, 4] research works. It is well know that the breakdown voltage of Ne pure is lower than the breakdown voltage of xenon pure, due to the fact that xenon is a heavy gas with a low secondary emission coefficient.

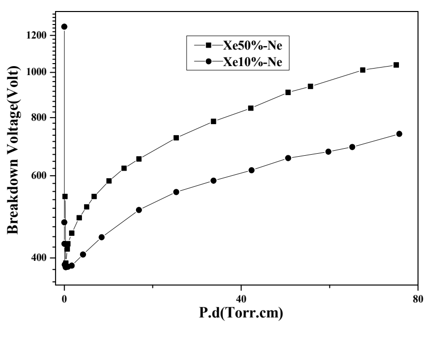

Fig.7. Influence of the Paschen curve in two gas mixtures: Xe50%-Ne and Xe10% -Ne, and for a plane geometry.

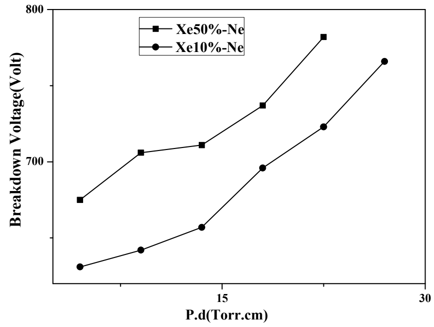

Fig.8. Paschen curve in different percentage of xenon for a coplanar geometry.

Summary and conclusions

The aim of this work is to study the electric discharge in the dielectric barriers for the two mixtures Xe50%-Ne and Xe10%-Ne, in a Planilux lamp with the aim of reducing the energy deposited in the discharge and therefore reducing the energy consumed by the lamp; we measured the breakdown voltage in the Xe-Ne mixture for this geometry. Note that there is a relationship between the light output energy of the lamp and the input energy, the total efficiency of the UV photon is obtained by the following relationship [27]

(1) $$\eta = E_t / E_{el}$$

E_{el} – electric energy, and E_t – the total energy

It is clear that when E_{el} decreases, η increases. This electric energy depends on the electric field and the interelectrode distance d according to the following relation [27]

(2) $$E_{el} = d \int_0^T E(t) I(t) dt$$

The *T* is the period, *I(t)* is the current discharge and the *d* is the interelectrode distance, the electric field *E* has a direct relation with the breakdown voltage according to the relation below [4]

(3) $$E = V_b / d$$

It seems clearly that for an optimal working energy E_{el} we realize a less expensive lamp.

To achieve this objective, we have shown that the geometry as well as the percentage of xenon in the gas mixture is important parameters. The increase in the percentage of xenon is responsible for the increases in U.V emission in the discharge, which leads to a high breakdown voltage. In the second part, we compared the two plane and coplanar geometries of this lamp. This comparison showed us that the plane geometry has a low breakdown voltage. We also carried out a parametric study on the role played by the frequency and the surface of the electrodes. It is assumed that as a function of the results found: the orders of magnitude of the breakdown voltage values obtained by all these parameters differ according to the working conditions and if the surface area of the electrodes is increased, the breakdown voltage decreases. We also noticed that the frequency does not have a big influence on the breakdown voltage. All these results allowed us to determine a series of physical parameters leading to the reduction of the breakdown voltage, and therefore the reduction of energy consumption.

Authors: *Dr. Fatiha GHALEB, Laboratoire de Physique des Plasmas Matériaux Conducteurs et leurs Applications, University of Sciences and Technology USTOMB, Algeria, E-mail: fatiha.ghaleb@univ-usto.dz; prof. Bruno CAILLER,* Laboratoire Diagnostic des Plasmas Hors Equilibre DPHE, Institut national Universitaire Champollion, Albi, France, E-mail: bruno.caillier@univ-jfc.fr; *prof.* Ahmed BELASRI, *Laboratoire de Physique des Plasmas Matériaux Conducteurs et leurs Applications, University of Sciences and Technology USTOMB, Algeria, E-mail: Ahmed belasri@yahoo.fr; prof. Soumia BENDELLA, Laboratoire de Physique des Plasmas Matériaux Conducteurs et leurs Applications, University of Sciences and Technology USTOMB, Algeria, E-mail: bendella.soumia@gmail.com.*

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