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Engineering and Construction

Factors That Affect Lichtenberg Figures

Name

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Background information

Lichtenberg Figures

Lichtenberg Figures are caused by electric discharges that sometimes occur on the surface of or inside insulating materials, such as wood, acrylic, or even human skin. German Physicist Georg Christoph Lichtenberg discovered them and subsequently researched them. In 1777, Lichtenberg built a large electrophorus to generate high voltage static electricity, after then discharging this high voltage he used pressed paper to record these patterns, this discovering the basic principle of xerography (What are Lichtenberg Figures? A bit of history..., 2020). These figures are of enormous interest because they exhibit fractal properties.

A fractal is a never-ending pattern which repeats itself at different scales. This property is called "Self-Similarity". Fractals are very complex; however, they are made by a straightforward repeating process. Fractals appear a lot in nature, such as in the shape of galaxies, hurricanes, and trees. One Fractal which is particularly well known is the Mandelbrot Set. What gives rise to these structures in nature? In this essay, I hypothesize what factors affect the formation of these Lichtenberg figures in insulating materials.

Main Body

The hypothesis I will discuss is that the following points affect the geometry of the Lichtenberg Figure; Distance between contact points, Duration of exposure, and Variation of material. As Lichtenberg Figures are caused by dielectric breakdown, changing these properties alter the electrodynamic properties of the material. By their very nature insulators do not readily allow current to flow through them, however in the case of dialectic breakdown, we can see that this must be occurring. This change in property occurs in insulators at their breakdown voltage, which is where an insulator becomes electronically conductive.

When solids-dielectrics are exposed to a strong electric field, failure occurs due to electrostatic forces which can exceed the mechanical compressive strength. We can also experience electrochemical breakdown; this is cavities in the material can also cause changes in the dielectric strength in the solid. When the gasses in the cavity break down, the surfaces inside the cavity provide instantaneous an anode and cathode. Electrons at the anode with enough energy break the chemical bonds of the insulation. A similar reaction occurs at the cathode. This provides some motivation behind my argument between different materials, i.e. wood and acrylic and the resulting Lichtenberg Figure.

We can express the mechanical compressive strength experienced by a sample of d0 in thickness is compressed to dc under an applied voltage V, where Y is the young's modulus of the material;

0rV22d=Yln d0dc

It's been noted that mechanical instability occurs when dd0=0.6 (Teella, 2011-2013). Using this information, we can now express the maximum apparent stress before breakdown as;

E =Vd0=0.6Y0r12

While this doesn't explicitly describe and explain the behaviour behind Lichtenberg Figures appearing in materials – it provides some clarity on the factors of the electrostatic forces which are experienced by dielectrics in an electric field. The fractal behaviours of Lichtenberg figures are tough to model mathematical; however, we can use the Generalized Dielectric Breakdown Model (GDBM) to explain this mathematically. This model states that there is no 'hard and fast' way to determine how these figures appear; however, it makes it clear that it is a probabilistic process. Materials with more regular structure create figures which are more 'perfect' than ones with irregular structures, and in the case of wood with air pockets, which give rise to electrochemical breakdown also. This verifies that my hypothesis for different materials be a valid one and be ideal for further testing.

My next hypothesis is time. In this probabilistic process, the 'characteristic time' has an important role to play, which I shall explain further. Let's introduce a parameter model parameter, , which is related to physical constants (for example, pressure and voltage). We can show that the leader discharge obeys a law, EE-η. The propagation rate, which is the rate of reaction, can be expressed as Ej1τ(Ej). We can express the probability of a new bond j to be chosen as pjEj, which gives rise to pj=E (Lanca, Dominigues, & Franco, 1995). So, this shows that the duration of the time of the material being subject to the electromagnetic field influence the formation and shape of the Lichtenberg figure.

My final hypothesis is that the distance between the two points of contact affect the formation of the Lichtenberg Figure. From what I have discussed previously in this document is clear that the distance affect. In for a point dipole, we can express the electric field strength as E$\propto$1r3, Which implies the further the points are the less the electric field strength be if the voltage is kept constant.

Conclusion

I have shown in this paper that my hypothesis that changing the material, exposure time, and distance between contact points affects the formation of the Lichtenberg Figures. While it must be noted that these formations are random and can only be modelled by statistical methods, we can show that the changing of these conditions will affect the parameters of the statistical model.

Bibliography

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