

Volumetric Lichtenberg Figures in PMMA

Background:

The first Lichtenberg figures were demonstrated by the German physicist, Georg Christoph Lichtenberg, in the late 1700's. The figures Lichtenberg discovered were two dimensional patterns on an electrostatically charged dielectric plate. He later incorporated into his physics class lectures, the techniques of formation for these lightning like images. The principles involved in the formation of these 2D electrostatic figures were later developed into modern xerography.

Material:

Lichtenberg figures can be made in a three dimensional form using a volume or bulk insulating polymer. Because of the very large number of insulating polymers in use, one type had to be settled upon with the best of all features. The polymer chosen to concentrate on was PMMA or Polymethyl methacrylate, mainly for its strength, good optical properties, fairly good thermal properties, ease of machining, availability and relatively low cost. PMMA (which is more commonly known as *acrylic*) has been around for a while and its properties are well documented. There are also small variations in the acrylic formulations produced by different manufacturers.

Description:

A 3D Lichtenberg figure is formed when a block of acrylic is irradiated by an electron beam from a linear accelerator or other type of electron accelerator. The electrons must be accelerated to relativistic velocities in order for them to gain enough kinetic energy to be forced into the volume of the acrylic. This will allow a very large space charge to build up in the interior of the acrylic. Acrylic has a fairly high dielectric strength, so a large amount of energy is needed to force the electrons in through this high impedance. Also, the same high dielectric strength keeps the electrons trapped inside the material. Electron beam energies in the range of about 1 MeV to 17 MeV are needed for sample blocks of acrylic with thicknesses ranging from about 0.125 inch to 4.0 inches. (Note: Energies at and above 8 MeV cause the carbon in the acrylic to undergo neutron activation which produces the carbon 11 isotope.) Electron beam dosages of around 0.5 MRad will give an adequate space charge density for good pattern formation. The samples may be irradiated in the ordinary air that would be found in a radiation shielded target room. First, the sample is placed in the electron beam with the correct beam parameters set. The piece is left in the beam until it has received the proper dosage. The beam is then turned off and the sample retrieved for discharge. At this point the sample is full of charge and at an extremely high electric potential energy. By adding a small amount of mechanical energy in the form of a tap with a sharp point, the charge will then be able to escape the boundaries of the dielectric into the surrounding air thus lowering the potential energy of the system. Discharging the sample after irradiation is referred to as post stressing. The sample may also be mechanically stressed in the same way before irradiation, which is known as prestressing. Generally, post stressing will produce a fractal like discharge pattern, while prestressing will produce a chaotic like pattern. Another way in which the sample may discharge is spontaneously during irradiation. While in the beam, a sample may discharge before acquiring the total dose usually because of a small undetectable stress, strain or nonuniformity in the material. These types of discharges tend to yield fractal like patterns. It is these nonuniformities in the material that concentrate the electric

field from the space charge and that determine the discharge point in the sample. It is believed that the entire discharge process takes on the order of 20 nsec to occur. The discharge is also accompanied by a bright white flash of light and a loud bang. The pattern formed is a permanent record of the discharge path taken and is made up of ever smaller conchoidal fractures. A region of undamaged material exists just inside the boundary surfaces. This is due to the fact that the charge is able to leak off at a rate greater than it is accumulated in this region because of being too close to the air / acrylic dissimilar dielectric interface. During irradiation the acrylic will become solarized. This is caused by the bremsstrahlung or braking radiation from the decelerating electrons. The relativistic electrons give up their energy in the form of electromagnetic radiation ranging from the X-rays to gamma rays. This bremsstrahlung is itself ionizing radiation which is in turn absorbed by the acrylic causing color centers in the molecular structure to form. This causes the material to selectively transmit light; hence, it takes on a transmissive color. This color will fade back to water clear with gentle heating or with just time.

Experiments:

A better understanding of this type of dielectric breakdown phenomena could be quite beneficial to the areas of physics, chemistry, high voltage engineering, spacecraft engineering and radiation environmental engineering. There are four basic types of experiments that could be done to characterize the physics of this phenomenon. The first is to use a high powered optical microscope fitted with a micrometer adjustment X-Y stage, measuring reticles, video and still camera mounts, and a polariscope for photoelastic stress analysis. The second is to use an ultra high speed framing camera to capture the pattern formation sequences of the different types of discharges. This framing camera would have to have a speed of around 4 nsec per frame for 5 frames. The third is to use an IR to UV spectrophotometer for a spectral analysis of the bright “white” light flash that occurs during actual dielectric breakdown. The fourth is to use an appropriate mathematical modeling software package to model the electric field strength distribution in the volume of a representative sample of acrylic slightly before irradiation, (to get a clear $t = 0$), during irradiation and discharge, and slightly after discharge, (to get a clear follow through). This particular model would only apply to the samples that undergo spontaneous discharge.

Several papers have been written on the topic of dielectric breakdown, but mainly in the areas of vacuum discharges, gaseous discharges, including lightning studies, and dielectric liquid discharges. Of the papers found written on dielectric breakdown in solids, very few cover the more specific topic of this particular type of failure mode in PMMA. At best, only a brief mention with a few details are given on this topic. Because of the apparent gap in the published literature on this specific topic of interest, research needs to be carried out and documented for this important area of interest.

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