The Chemistry of Trees

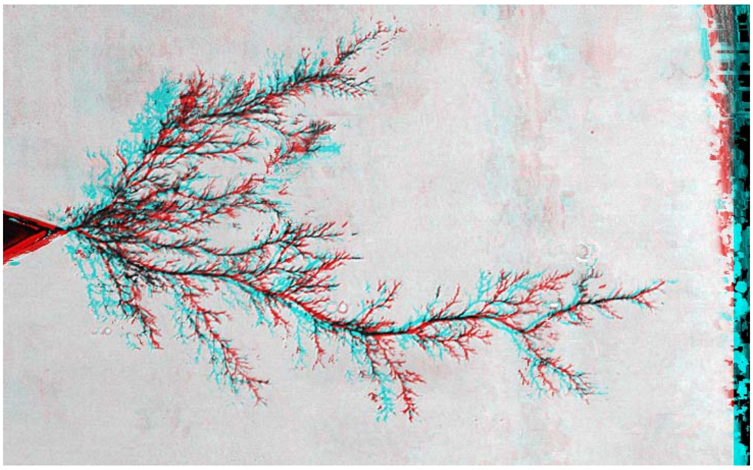

Figure 1. A lightly branched tree structure (pseudo 3-D red/green image).

Electrical treeing is a dielectric breakdown process of both academic and technological importance, in which a fractal structure of fine erosion channels develops through progressive partial discharge activity. Figure 1 shows a pseudo 3-D red/green image of a tree. In this, the high voltage needle electrode can be seen at the left of the figure and the planar ground earth electrode at the right. The electrode separation is 2 mm. The electrical properties of trees are determined by their chemistry, and confocal Raman spectroscopy provides a means of obtaining spectroscopic information with micron resolution from within such a structure.

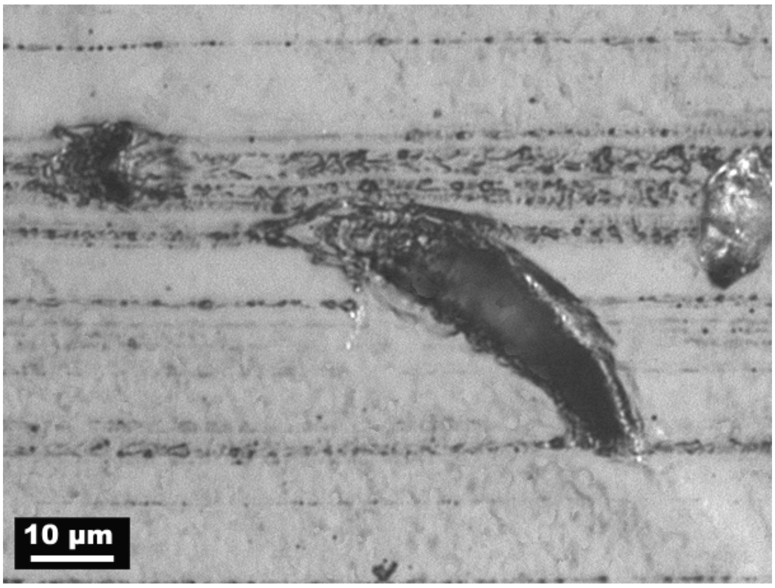

Figure 2. A single tree channel within a polyethylene specimen.

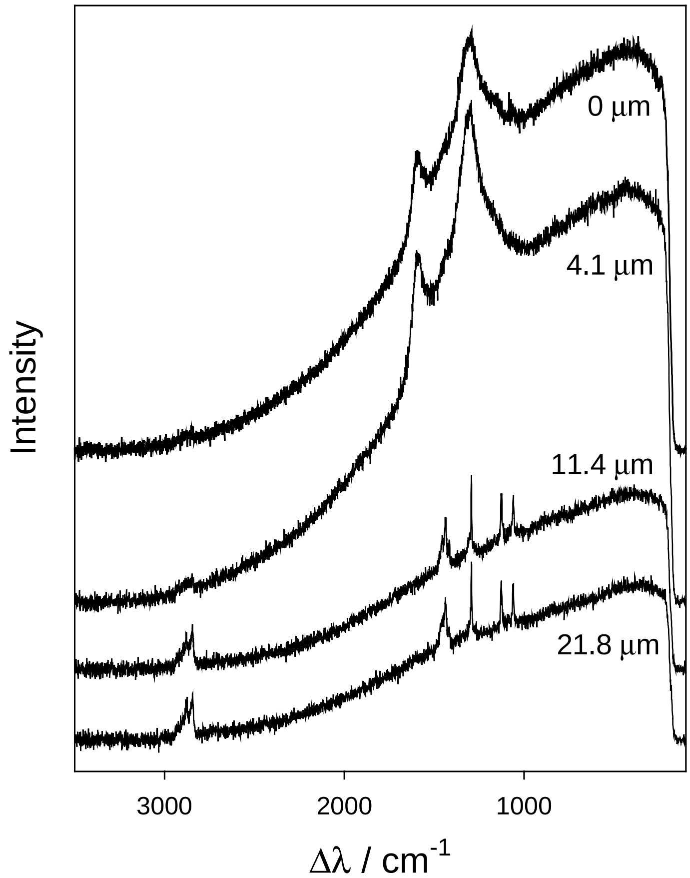

Figure 3. Raman data acquired from within, and adjacent to, the tree channel shown in figure 2.

Figure 2 shows a cross-section through a tree channel within an electrical tree grown in a block of low density polyethylene. Associated Raman spectra, acquired from a series of points the indicated distance from the axis of this channel, are shown in figure 3. Spectra acquired from the core of the channel are characterized by two distinctive Raman bands, at about 1560 and 1360 cm^{-1}, superimposed upon a fluorescent background. These are termed the G and D bands of carbon and are characteristic of systems that contain considerable amounts of sp^2 bonding. That is, they are indicative of disordered graphitic carbon. From the relative intensity of the 2 bands, we can estimate the average graphitic domain size within our tree channels to be ~ 4 nm, which implies a room temperature DC resistivity is of the order of 10^{-3} Ω cm and a resistance per unit length of the tree channel of 1-10 Ω μm^{-1}. These structures are therefore too conducting to allow discharge activity to occur within them.

Figure 4 shows a series of Raman spectra acquired from tree channels at located at different points within the structure; the distance from the high voltage electrode is shown in each case. Throughout the core of the tree, the spectra are characterized by the G and D bands of carbon – electrically these are equivalent to the feature discussed above. At the very tips of the tree, the spectra are characteristic of the polyethylene matrix, indicating that, here, tree channels take the form of simple tubules within the dielectric. At intermediate locations, the spectra contain, primarily, varying degrees of fluorescence. Specifically, the fluorescence increases as the core of the tree is approached and then, decreases, as the G and D bands appear. This implies that the fluorescent material may be associated with an intermediate stage in the conversion of polyethylene to graphitic carbon.

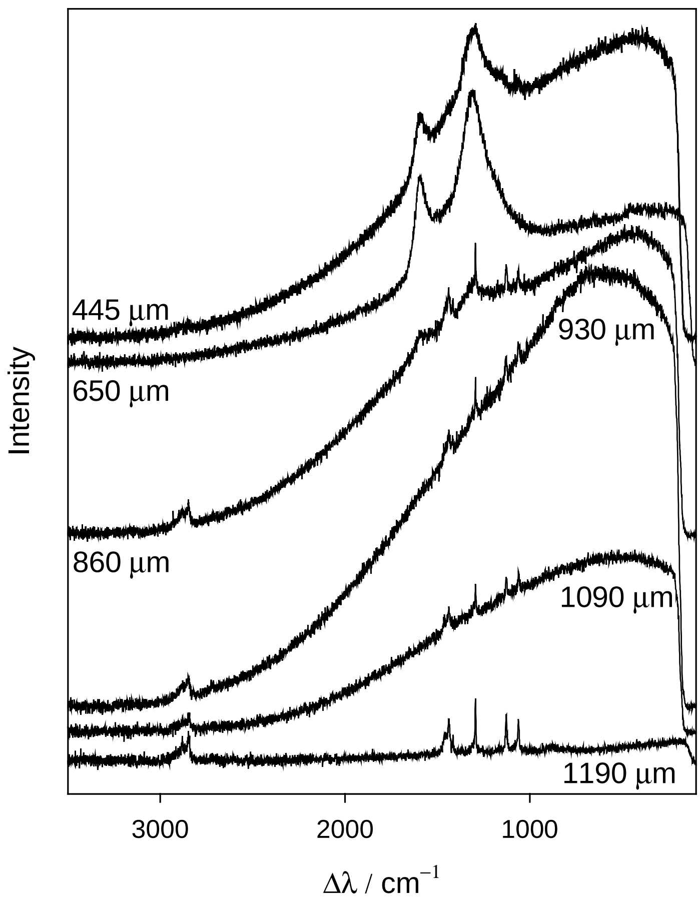

Figure 4. Raman spectra acquired from channels situated at different positions within the tree.

This description of tree chemistry is, however, not universal. In another type of tree, the transition from fluorescent material to disordered carbon does not occur. Rather, the extent of fluorescence increases massively as the high voltage electrode is approached. Since electrical conductivity is associated with graphitic carbon, these observations correlate well with the differentiation of trees into two types; conducting and non-conducting. But questions remain. What is the chemistry of the transition from fluorescent precursor to graphitic carbon? Why does this occur in certain trees and not in others?

For more information of Raman spectroscopy of trees see:

A.S.Vaughan, S.J.Dodd, S.J.Sutton, Electrical treeing in polyethylene: analysis by confocal Raman microprobe spectroscopy, 2003 Ann. Rep. CEIDP, New Jersey, IEEE, 2003, 534-537.

X.S.Liu, A.S.Vaughan, G.Chen, A Raman spectroscopic study of bulk and surface ageing phenomena in polyethylene, 2003 Ann. Rep. CEIDP, New Jersey, IEEE, 2003, 145-148.

A.S.Vaughan, S.J.Dodd, S.J.Sutton, A Raman microprobe study of electrical treeing in polyethylene, J. Mater. Sci. 2004, **39** (1), 181-191.
A.S. Vaughan, I.L. Hosier, S.J. Dodd and S.J. Sutton,On the structure and chemistry of electrical trees in polyethylene, submitted to J. Phys. D.
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