Affect of Photo-oxidation Products on Electroluminescence Emission and Conduction Current of LDPE

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Introduction

- Ageing of high voltage insulation
  - Interest in mechanisms behind ageing process
  - Improving dielectric design and life time estimation
  - Role of charge trapping and movement in material ageing.

- Artificial ageing
  - Generation of oxidation products and cross-linking
  - Affect on charge injection, trapping and recombination
Experiment

• Chosen a standard polymeric system
  – 100 µm low density polyethylene (LDPE) films
  – Ultraviolet ageing with peak emission of 253.7nm

• UV affect
  – Electrical changes and chemical structure
  – Charge movement in the bulk and near the electrode-polymer interface.
What is Electroluminescence?

- Low level light emission from electrically stressed polymers
- Bipolar recombination of charge carriers
  - AC stress, emission is thought to originate near the electrode-polymer interface.
  - Emission peaks in first and third quadrants
Ageing Process

- Experiment setup
  - 36 W UV fluorescent tube with peak emission at 253.7 nm
  - Samples mounted away from reflective back wall
  - Fan oven at constant 40 °C
  - 100 µm LDPE film
  - Aged in 3 and 7 day intervals up to 17 days.
Ageing Effects
Dielectric Strength

- ASTM D149 standard (50 Hz, 50 V/s ramp, 6.3 mm steel ball ball bearings)
- Reduced breakdown strength with ageing
- Reduced uniformity

<table>
<thead>
<tr>
<th>Sample Age</th>
<th>$\alpha$ Value (kV/mm)</th>
<th>$\beta$ Value</th>
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<tbody>
<tr>
<td>Virgin</td>
<td>160.1 ± 1.2</td>
<td>43.0</td>
</tr>
<tr>
<td>7 Days</td>
<td>154.4 ± 2.5</td>
<td>19.9</td>
</tr>
<tr>
<td>17 Days</td>
<td>151.1 ± 2.7</td>
<td>17.7</td>
</tr>
</tbody>
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2 Parameter Weibull Distribution

$$P_f(x) = 1 - \exp \left[ - \left( \frac{x - x_i}{\alpha} \right)^\beta \right]$$
FTIR spectra – Oxidation Products

- Increased Carbonyl and Hydroxyl groups
- No effect due to 40 °C temperature
- Chemical (deep) trapping sites
Dissolving in Xylene – Cross-linked

- Samples dissolved in boiling Xylene for 1 hour and then dried.

- Initially large increase in cross-linking

- Cross-linking reduces as ageing time continues
Charge Transport
Pulsed Electro-Acoustic (PEA) Experiment

- 40 minutes charging, 20 minutes decay
- 40 kV/mm dc field, calibrated at 10 kV/mm
- Top electrode – semiconducting polymer
- Bottom electrode - aluminium

400V, 2.5ns pulse
PEA Results

Virgin LDPE

UV Aged 3 days

UV Aged 7 days

UV Aged 10 days

UV Aged 14 days

UV Aged 17 days
Total Bulk Charge

During Electrical Stressing

- Virgin LDPE
- UV Aged 3 days
- UV Aged 7 days
- UV Aged 10 days
- UV Aged 14 days
- UV Aged 17 days

After Electrical Stressing
Electroluminescence
Electroluminescence Experiment

- Experiment under dry nitrogen at 1 bar above atmospheric.
- 50 Hz, sinusoidal field.
- Gold sputter coat ~20 nm each side.
- Total EL emission during 1 ac cycle, averaged over 100 cycles.
Electroluminescence Results

- Increased EL and cross-linking initially.
- Increased cross-linking maintained, reduced EL with further ageing.
Electroluminescence Results

- Carbonyl absorbance taken at 1714 cm$^{-1}$
- Oxidation products are seen to increase with ageing time.
Electroluminescence Results

- Measured bulk charge after 40 minutes.
- Initially bulk charge reduces up to 7 days.
- Further ageing increases bulk charge.
Conclusions

• This initial work aims to improve understanding in the role of charge movement in the ageing of high voltage insulation

• LDPE was UV aged, resulting in:
  – A reduction in dielectric strength
  – Increased cross-linking
  – Increased oxidation products
Conclusions Continued

• Experiments to investigate charge movement showed:
  – Initially less charge is trapped within the bulk but this increases with further ageing.
  – Initially stronger electroluminescence but this reduces with further ageing.

• A build up of charge traps near the electrode-polymer interface limits charge injection into the bulk. Continued ageing shows greater oxidation allowing for charge injection and trapping within the bulk of the polymer.