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Published in:
Journal of Physics D: Applied Physics

DOI:
10.1088/0022-3727/49/2/025305

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication in Discovery Research Portal

Citation for published version (APA):

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Positron annihilation lifetime spectroscopy study of Kapton thin foils

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Received 6 July 2015, revised 2 September 2015
Accepted for publication 11 September 2015
Published 1 December 2015

Abstract

Variable energy positron annihilation lifetime spectroscopy (VE-PALS) experiments on polyimide material Kapton are reported. Thin Kapton foils are widely used in a variety of mechanical, electronic applications. PALS provides a sensitive probe of vacancy-related defects in a wide range of materials, including open volume in polymers. Varying the positron implantation energy enables direct measurement of thin foils. Thin Kapton foils are also commonly used to enclose the positron source material in conventional PALS measurements performed with unmoderated radionuclide sources. The results of depth-profiled positron lifetime measurements on 7.6 \( \mu \)m and 25 \( \mu \)m Kapton foils are reported and determine a dominant 385(1) ps lifetime component. The absence of significant nanosecond lifetime component due to positronium formation is confirmed.

Keywords: positron annihilation, polymers, positron annihilation lifetime spectroscopy

(Some figures may appear in colour only in the online journal)
The measurements on the 25 μm and 7.6 μm Kapton exhibit a single dominant positron lifetime component with an intensity of greater than 99.3%, and a second negligible intensity nano-second component. The lifetimes obtained for the dominant component are shown in figure 2, the average value is 357(3) ps for 25 μm Kapton and 369(3) ps for 7.6 μm Kapton. Measurements using three different polymers obtained values of 354 ps, 358 ps and 368 ps for Kapton, PMDA-ODA and PI2540 respectively. The lifetime component at 369(3) ps is the result of an artefact of the spectrum analysis that arises when the lifetime decomposition were reported to give the best fits. The nature of the multi-component analysis is described by a Makhovian profile, with the median depth of implantation being 7.6 μm for 25 μm Kapton and 17.1 μm for 7.6 μm Kapton. The mean implantation depth increases with increasing implantation energy, for 10 keV monoenergetic positrons it is approximately 1 μm.

3. Results and discussion

The measurements on the 25 μm and 7.6 μm Kapton were performed using a high energy positron beam, fitted the resulting spectra using two positron lifetime components and two associated Doppler broadening spectroscopy (DBS) S-parameter values [14]. The lifetime components were reported to be 229 ps and 378 ps, the latter with an intensity of 87%; the nature of the Makhovian profile, with the median depth of implantation being 7.6 μm for 25 μm Kapton and 17.1 μm for 7.6 μm Kapton. The mean implantation depth increases with increasing implantation energy, for 10 keV monoenergetic positrons it is approximately 1 μm.

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385(1) ps. Figure 1 shows representative Markovian implantation profiles demonstrating that the positrons were confined to the Kapton foils for all implantation energies used. Implantation energies of 16 keV and 18 keV were selected for the 7.6 μm Kapton as the resulting depth distributions optimally sample the foil and provide lifetime values of direct relevance to conventional PALS experiments using Kapton supported positron sources.

These results provide clear evidence for a dominant single positron lifetime component with a value of 385(1) ps in Kapton HN for both foil thickness studied. This is in agreement with the early bulk PALS reports of a single lifetime value of 382 ps [16], and 382(3) ps [10], and with the most recent study giving 385(3) ps [13]. The measurements provide further evidence that previously reported two component fits result from an artefact of the fitting process [11, 12, 14]. The AMOC results require the existence of at least two positron states [14], but are complicated by in-flight annihilation and by the high (3.5 MeV) positron energy and hence the requirement for thick samples. The low values reported for Kapton PI2540 of ~354 ps suggest that this is different to Kapton HN [8]. The low average lifetime for Kapton HN of ~370 ps reported by McGuire and Keeble [12], resulted from incorrect 22NaCl source correction, the value obtained by applying a systematic source correction procedure was reported to be 385(4) ps [6].

These measurements demonstrate that conventional, bulk, positron lifetime measurements using radionuclide positron sources supported thin Kapton HN foils can be analysed by fixing the lifetime of the foil source correction component to a value of 385(1) ps. The results of Hirade et al [13], suggest that this value may decrease with time for high activity sources.

4. Conclusions

Positron lifetime spectra were directly measured from 7.6 μm and 25 μm Kapton HN foils with VE-PALS using implantation energies for which all the positrons annihilate from within the foil. A single dominant lifetime component with an intensity greater than 99% was obtained from all measurements with a lifetime value of 385(1) ps.

Acknowledgments

D J K acknowledges European Commission Programme (RI3-CT-2003–505925), G S K was supported by an EPSRC DTA studentship (EP/J500392/1).

References