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# Positron Lifetime in Hostaphan

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Positron lifetime measurements in hostaphan RNK, used for encapsulation of $^{22}$Na positron sources, were performed. It was found that the parameter of positron lifetime spectra in hostaphan RNK differ markedly from those for other forms of polyethylene terephthalate. The maximum penetration depth of positrons from RNK hostaphan amounts 0.42 mm. The information gained in the present study is of great importance for experimenters using hostaphan RNK for encapsulation of positron sources.

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## 1. Introduction

Hostaphan is the registered trademark for Mitsubishi polyester film consisting of polyethylene terephthalate (PET). Depending on its processing and thermal history, it may exist both as an amorphous (transparent) and as a semicrystalline (opaque and white) material. It can be synthesized by a transesterification reaction between ethylene glycol and dimethyl terephthalate. PET is a hard, stiff, strong, dimensionally stable material that absorbs very little water. It has good gas barrier properties and good chemical resistance except to alkalis (which hydrolyse it). It is widely known in the form of biaxially oriented and thermally stabilized films usually referred to by their main brand names Mylar, Melinex or Hostaphan. Strictly speaking, these names should be used only for this type of film whose properties are different from, and in several respects superior to, those of "ordinary" PET film. These "Mylar-type" films are used for capacitors, graphics, film base and recording tapes etc. PET is also used for fibres, for a very wide range of textile and industrial uses (Dacron, Trevira, Terylene). Other applications include the production of different bottles, fibers, films for food packaging, and in medicine for plastic vessels and for implantation.

In positron annihilation lifetime (PAL) spectroscopy hostaphan is used to hermetically encapsulate positron source. In that application hostaphan foils

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should be transparent for positrons and impermeable for radioactive isotope ($^{22}$Na). These are oppose demands and dependently on thickness of foils the capsule can be more transparent or more hermetic. In our laboratory the investigations of stretching and corroding samples are carried out, therefore it is important to have hardly and strongly encapsulated source. Multi-layer hardened "Hostaphan RNK" of thickness of 20 $\mu$m satisfactory fulfill our requirements.

The present paper deals with a study of PAL parameters dependence on the thickness (number of foils) of investigated hostaphan. The analysis of PAL spectra enable to characterize lifetime components as well as maximum range of penetration of hostaphan by positrons. The profile of positron absorption within the investigated material is characterized, too.

## 2. Experimental details

The hostaphan RNK that we had to our disposal is a highly transparent, biaxially oriented, coextruded film characterized by density of $1.4 \times 10^3$ kg/m$^3$ and thickness of 20 $\mu$m. The square samples of area of 4 cm$^2$ were cut from A4 sheets. Full list of physical properties of hostaphan RNK is presented in [1].

Positron annihilation lifetime spectra were obtained using a fast-slow coincidence spectrometer with $BaF_2$ scintillators. The time resolution of the device was determined as the value of full weight at half maximum (FWHM) of resolution curve (one Gaussian) given by lifetime computer program (LT) [2] for each of the spectra. The average value of FWHM determined from 31 spectra amounts 267 ps. The 90° geometry of detectors was applied. A 20 $\mu$Ci $^{22}$Na positron source sealed by hostaphan foils was placed between two plates of the same samples. At first, the PAL spectrum for aluminum (4N) samples was collected. Then, the measurement with hostaphan RNK foils put additionally between aluminum and positron source at each side of the source was taken. In successive measurements additional samples of hostaphan RNK were added till to 31 foils on each side of the positron source. At least one million of counts were collected for each of the spectra.

## 3. Results and discussion

PAL spectra were deconvoluted into three components although there was supposition that apart from three hostaphan RNK components there is one characteristic of aluminum. The attempt of decomposition into four (not fixed) components failed. All the results of analysis of positron lifetime data made with use of LT computer program are presented in Table I, where average positron lifetimes and intensities of free components as well as test of the fit ($\chi^2$) and FWHM of resolution curve are presented. Additionally, we calculated the average positron lifetime from the formula

$$\tau_{\mathrm{av}} = \frac{\tau_1 I_1 + \tau_2 I_2 + \tau_3 I_3}{I_1 + I_2 + I_3}. \tag{1}$$

TABLE I

The average positron lifetimes $\tau_1$, $\tau_2$, $\tau_3$, and intensities $I_1$, $I_2$, $I_3$ of the components as well as test of the fit ($\chi^2$) and FWHM of resolution curve are presented. Additionally, the table contains the average positron lifetime calculated using the formula (1). Standard deviations of measured quantities are given in round brackets. $N$ — number of foils.

| $N$ | $\tau_1$ [ps] | $I_1$ [%] | $\tau_2$ [ps] | $I_2$ [%] | $\tau_3$ [ps] | $\tau_{av}$ [ps] | $\chi^2$ | FWHM [ps] |
|---|---|---|---|---|---|---|---|---|
| 1 | 144.4(3.2) | 66.8(1.6) | 324(10.0) | 28.6(1.6) | 1934(56) | 278(13) | 0.987 | 262.3 |
| 2 | 151.6(3.7) | 62.5(1.6) | 338(10.0) | 31.5(1.6) | 1914(32) | 316(14) | 1.019 | 262.1 |
| 3 | 153.9(2.8) | 59.1(1.1) | 344(6.8) | 33.7(1.2) | 1878(17) | 342(10) | 1.061 | 263.9 |
| 4 | 148.6(0.8) | 50.5(0.5) | 338(3.5) | 41.3(1.2) | 1882(23) | 369(7) | 1.049 | 267.2 |
| 5 | 160.7(5.0) | 50.7(1.8) | 349(10.0) | 40.1(1.9) | 1803(34) | 387(20) | 1.059 | 267.2 |
| 6 | 160.8(6.0) | 46.3(2.0) | 345(9.9) | 43.8(2.0) | 1793(32) | 403(22) | 1.008 | 269.9 |
| 7 | 163.1(6.2) | 45.2(2.0) | 358(10.0) | 44.2(2.0) | 1909(36) | 434(24) | 0.987 | 267.5 |
| 8 | 169.6(7.0) | 45.0(2.3) | 360(12) | 43.7(2.3) | 1898(31) | 448(28) | 1.020 | 265.5 |
| 9 | 170.1(7.1) | 43.1(2.3) | 361(12) | 45.2(2.3) | 1814(33) | 449(29) | 1.022 | 266.2 |
| 10 | 159.7(7.3) | 36.2(2.0) | 348(8.3) | 51.7(1.9) | 1825(28) | 456(25) | 1.050 | 266.9 |
| 11 | 173.2(9.3) | 38.7(2.8) | 358(12) | 49.0(2.7) | 1837(26) | 468(33) | 0.930 | 265.7 |
| 12 | 178.0(9.0) | 38.3(2.6) | 364(11) | 48.9(2.5) | 1838(24) | 481(32) | 1.009 | 266.4 |
| 13 | 157.0(10.0) | 27.9(2.0) | 339(5.9) | 58.6(1.8) | 1801(22) | 485(25) | 1.012 | 266.6 |
| 14 | 187.0(12.0) | 38.2(3.7) | 370(16) | 48.7(3.5) | 1860(30) | 495(46) | 1.075 | 265.2 |
| 15 | 174.2(1.1) | 31.7(0.1) | 356(1.5) | 54.6(0.1) | 1787(7.6) | 494(4) | 1.110 | 266.4 |
| 16 | 154.4(12.0) | 23.8(2.4) | 339(7.4) | 62.3(2.2) | 1770(25) | 494(30) | 1.016 | 267.6 |
| 17 | 176.9(7.7) | 29.1(2.0) | 354(6.3) | 57.2(1.8) | 1801(11) | 501(23) | 1.157 | 267.1 |
| 18 | 194.0(11.0) | 33.3(3.3) | 364(11.0) | 52.9(3.2) | 1826(24) | 509(39) | 1.095 | 264.8 |
| 19 | 165.5(9.9) | 21.9(2.0) | 341(5.5) | 63.6(1.8) | 1744(20) | 505(25) | 1.129 | 267.2 |
| 20 | 188.0(14.0) | 27.7(3.7) | 356(11.0) | 57.7(3.4) | 1779(31) | 517(45) | 1.040 | 267.8 |
| 21 | 181.0(18.0) | 22.5(4.1) | 343(10.0) | 62.5(3.6) | 1743(29) | 517(48) | 1.057 | 267.1 |
| 22 | 183.0(13.0) | 23.3(3.1) | 347(8.0) | 61.7(2.8) | 1787(20) | 525(37) | 1.014 | 268.1 |
| 23 | 193.0(16.0) | 26.9(4.1) | 357(11.0) | 58.3(3.8) | 1824(25) | 530(49) | 1.027 | 265.8 |
| 24 | 199.0(15.0) | 30.0(4.2) | 365(13.0) | 55.2(3.9) | 1812(26) | 529(51) | 1.055 | 267.7 |
| 25 | 198.0(17.0) | 27.3(4.5) | 360(12.0) | 57.9(4.2) | 1803(25) | 529(53) | 1.091 | 268.3 |
| 26 | 202.0(18.0) | 23.9(4.6) | 354(11.0) | 61.2(4.1) | 1809(19) | 534(52) | 1.023 | 268.7 |
| 27 | 206.0(15.0) | 27.8(4.2) | 363(11.0) | 57.4(3.9) | 1849(21) | 539(50) | 1.079 | 269.5 |
| 28 | 209.0(18.0) | 27.7(5.4) | 358(13.0) | 57.1(5.0) | 1806(17) | 537(61) | 1.042 | 267.8 |
| 29 | 199.0(15.0) | 24.7(3.7) | 359(9.4) | 60.5(3.4) | 1827(19) | 537(43) | 1.107 | 269.9 |
| 30 | 182.0(15.0) | 21.2(3.4) | 345(8.0) | 63.2(3.0) | 1769(13) | 532(39) | 1.109 | 268.1 |
| 31 | 201.0(19.0) | 22.5(0.5) | 355(10.0) | 62.6(4.2) | 1822(16) | 539(38) | 1.047 | 270.6 |

Relating the obtained results to the data previously used in our laboratory, characteristic of hostaphan: $\tau_1 = 158$ ps, $I_1 = 22.8\%$, $\tau_2 = 394$ ps, $I_2 = 56.5\%$, $\tau_3 = 1660$ ps, $I_3 = 20.7\%$ and taking into account the value of positron lifetime characteristic of aluminum (163 ps [3]) we treat the third component as originating only from annihilations within hostaphan RNK. However, the first and the second components include information about annihilations within hostaphan RNK as well as within aluminum, particularly for not large number of hostaphan RNK foils used in the experiment.

The increase in intensity of the third component as a function of the increase in thickness of hostaphan RNK used in the experiment confirms the hypothesis that some of positrons annihilate within aluminum (Fig. 1).

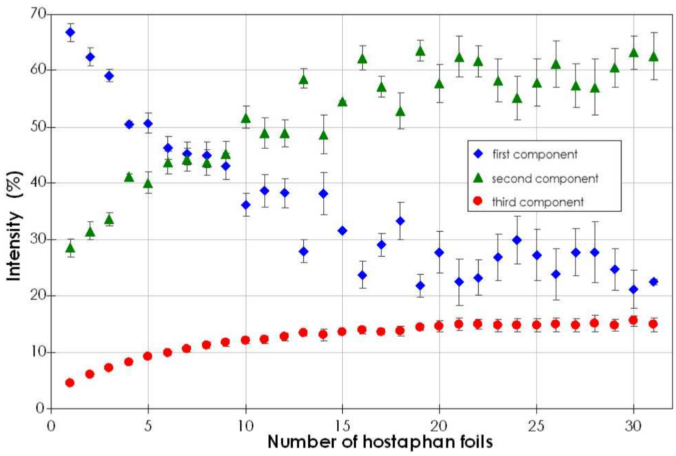


Fig. 1. The intensities of positron lifetime components as a function of number of hostaphan RNK foils.

Within the range from about 22 to 31 of foils the intensities of all the three components become nearly constant. It means that further adding of hostaphan RNK foils does not change the registered spectra and we can assume that nearly all positrons annihilate within hostaphan RNK, not in aluminum. Therefore the values of annihilation parameters for the range of 22–31 of foils are characteristic only of hostaphan RNK and the average values of lifetimes and intensities can be expressed by the (2) and (3) formula, respectively

$$\tau_{\mathrm{av}} = \left(\sum_{k_0=22}^{k=31} \tau_{n_k}\right) \frac{1}{k-k_0}, \tag{2}$$

$$I_{\mathrm{av}} = \left(\sum_{k_0=22}^{k=31} I_{n_k}\right) \frac{1}{k-k_0}, \tag{3}$$

where $n$ — component number, $k$ — number of foils.

TABLE II

Positron lifetimes and intensities for hostaphan RNK in comparison with previously used values for hostaphan.

| Annihilation parameters for hostaphan RNK | | | | | |
|---|---|---|---|---|---|
| $\tau_1$ [ps] | $I_1$ [%] | $\tau_2$ [ps] | $I_2$ [%] | $\tau_3$ [ps] | $I_3$ [%] |
| 197(16) | 25.5(3.77) | 356(11) | 59.5(3.83) | 1811(20) | 15.0(1.13) |
| Annihilation parameters for previously used hostaphan | | | | | |
| 158 | 22.8 | 394 | 56.5 | 1660 | 20.7 |

The calculated values of lifetimes and intensities are presented in Table II.

The intensities of the first component are nearly opposite to those for the third component. It is connected with lowering of the number of annihilations within aluminum with increasing number of hostaphan RNK foils. The first lifetime component corresponds mainly to annihilations of positrons within aluminum therefore decreasing tendency of $\tau_1$ was expected. Decrease in intensity of the second component observed with increasing number of hostaphan RNK foils reflects the fact that this component cannot be attributed only to annihilations within hostaphan RNK.

Changes of values of $\tau_2$ and $\tau_3$ for small number of hostaphan foils (Figs. 2, 3) confirms the opinion about unability of LT program to distinguish between aluminum and hostaphan channels of annihilation.

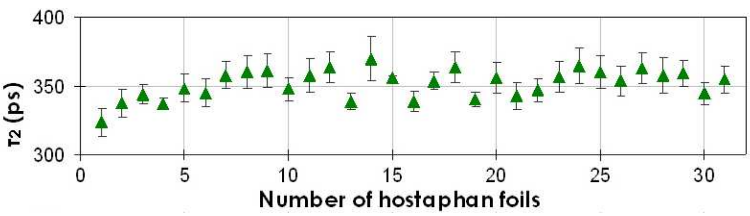


Fig. 2. The positron lifetime of the second component as a function of number of hostaphan RNK foils.

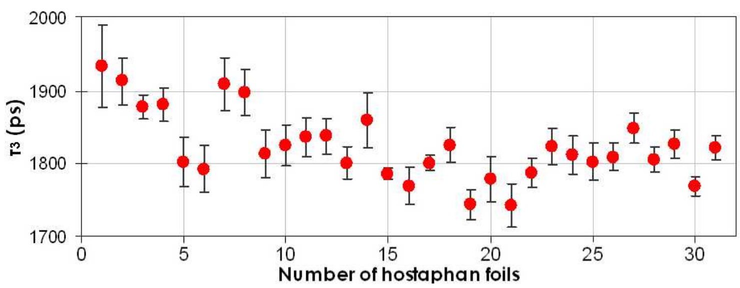


Fig. 3. The positron lifetime of the third component as a function of number of hostaphan RNK foils.

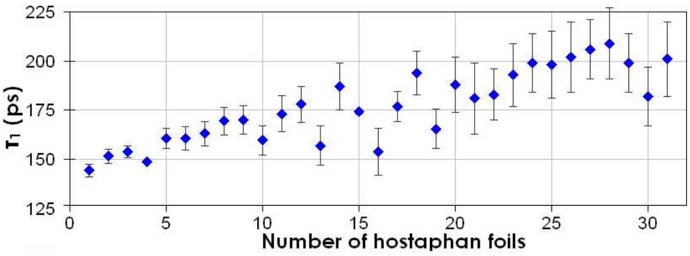


Fig. 4. The positron lifetime of the first component as a function of number of hostaphan RNK foils.

A bit larger than average values of $\tau_3$ within the range of 1–8 foils cause that corresponding values of the first component are a bit smaller than expected (Fig. 4).

Before and after the series of measurements the control measurements only for aluminum samples were made. The received values of not fitted component of 164 ps and 161 ps with standard deviation for both results amounting 1 ps confirm the proper state of spectrometer during measurement session.

Nearly the same values of $\tau_{\mathrm{av}}$ parameter received for number of foils within the range of 22 to 31 confirm the saturation of annihilation within hostaphan RNK. It is the base of estimation of maximum penetration depth of positrons in the investigated material. Positrons penetrate hostaphan RNK to the thickness of about 0.42 mm.

The measurement of annihilation parameters for total used thickness 0.62 mm (31 foils) of hostaphan RNK was repeated after half a year. The received results, within the range of statistical errors, are the same.

## 4. Conclusions

Through complementary information obtained from positron annihilation lifetime measurements it was evidenced that:

- there are a bit different values of average positron lifetimes and intensities of positron lifetime components for the hostaphan RNK in comparison with previously used values for hostaphan,
- the saturation of annihilation was observed for thickness of hostaphan RNK greater than 0.42 mm.

## References

[1] Mitsubishi Polyester Film, http://m-petfilm.com/Europe/PDF/Datasheets/Englisch/RNKe.pdf.

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[3] A. Seeger, F. Banhart, W. Bauer, in: *Positron Annihilation*, Eds. L. Dorikens-Vanpreat, M. Dorikens, D. Segers, World Scientific, Singapore 1989, p. 275 and references therein.