Variety of positron-electron annihilation kinetics in modified MgO–Al$_2$O$_3$ ceramics in the frequency domain

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Introduction

Positron-electron annihilation (PEA) kinetics in the MgO-Al$_2$O$_3$ ceramics sintered at different temperatures (1100, 1200 and 1400 °C) with following water adsorption procedure has been calculated and analyzed in a frequency domain. The spectra of real (in-phase) $\chi_1(\omega)$ and imaginary (quadrature) $\chi_2(\omega)$ components of modulated positron-electron annihilation response have been obtained numerically from temporal kinetic characteristics using integral Fourier transform. The obtained complex spectra of positron-electron annihilation in MgO-Al$_2$O$_3$ ceramics in the frequency domain obey a sum of two Debye law components denying correlation between elementary positron annihilation processes. Strong increasing of amplitude of lower frequency Debye component caused by water adsorption on the frequency spectra has been observed. Characteristic frequencies of Debye type components of water immersed samples show weaker dependencies on sintering temperature than in just sintered ones. It's shown that position of large maxima on the frequency dependencies of imaginary part corresponds to the fastest average relaxation lifetime representing the most intensive interaction process of positrons with small cavities traps in solids.

Calculation methods

Integral Fourier transform gives a connection between impulse characteristic $h(t)$ of PEA kinetics in the time domain and complex modulated PEA spectra in the frequency domain:

$$\chi_1(\omega) = \int_0^\infty h(t)\cos(\omega t)\,dt \qquad \chi_2(\omega) = \int_0^\infty h(t)\sin(\omega t)\,dt$$

Reverse integral Fourier relations can be used to obtain the frequency spectra of modulated PEA in solid that have not been measuring directly till now.

Assuming that impulse characteristic $h(t)$ of water-immersed ceramic samples similar to just-sintered ones obeys a sum of Debye law components (characterizing by exponential decay in the time domain), $h(t)$ may be written in the form:

$$h(t) = -\frac{I_1}{\tau_1}\exp\left(-\frac{t}{\tau_1}\right) - \frac{I_2}{\tau_2}\exp\left(-\frac{t}{\tau_2}\right) - \frac{I_3}{\tau_3}\exp\left(-\frac{t}{\tau_3}\right)$$

with intensities I_1, I_2, I_3 and corresponding relaxation times τ_1, τ_2, τ_3 in the case of three components.

PEA data

Fitting parameters and average positron lifetime for just-sintered and water-adsorbed MgO-Al$_2$O$_3$ ceramics sintered at different T_s reconstructed from three-component decomposition procedure

| T_s, ºC	Pre-history	τ_1, ns	I_1, a. u.	τ_2, ns	I_2, a. u.	τ_3, ns	I_3, a. u.	τ_{av}, ns
1100	just-sintered	0.24	0.68	0.50	0.30	2.59	0.02	0.32
	water-adsorbed	0.24	0.56	0.50	0.29	1.88	0.15	0.33
1200	just-sintered	0.23	0.70	0.47	0.28	2.39	0.02	0.30
	water-adsorbed	0.22	0.54	0.45	0.34	1.87	0.12	0.31
1400	just-sintered	0.19	0.76	0.36	0.22	1.90	0.02	0.24
	water-adsorbed	0.21	0.56	0.43	0.32	1.94	0.12	0.29

Modulated PEA complex spectra
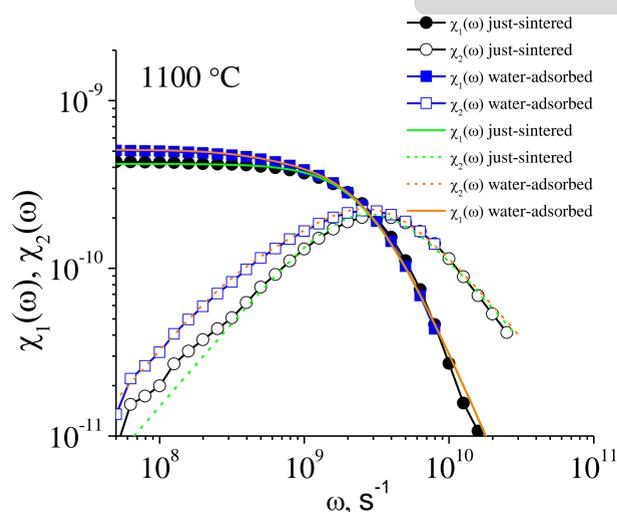
Modulated PEA complex spectra of just-sintered and water-adsorbed MgO-Al$_2$O$_3$ ceramics obtained at 1100°C (solid lines – fit according to Debye law)
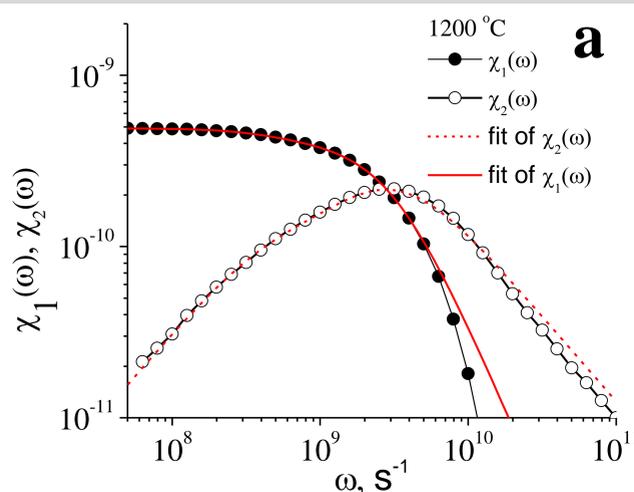
Modulated PEA complex spectra of water-adsorbed MgO-Al$_2$O$_3$ ceramics obtained at 1200 (a) and 1400 °C (b): red lines corresponds to fitting results by the sum of two Debye type components
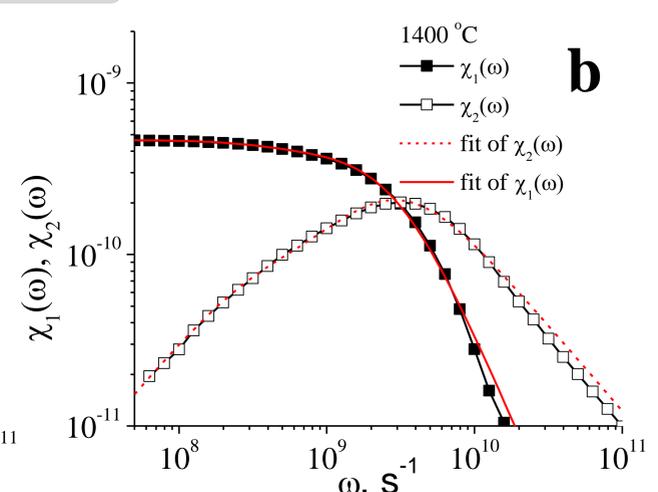
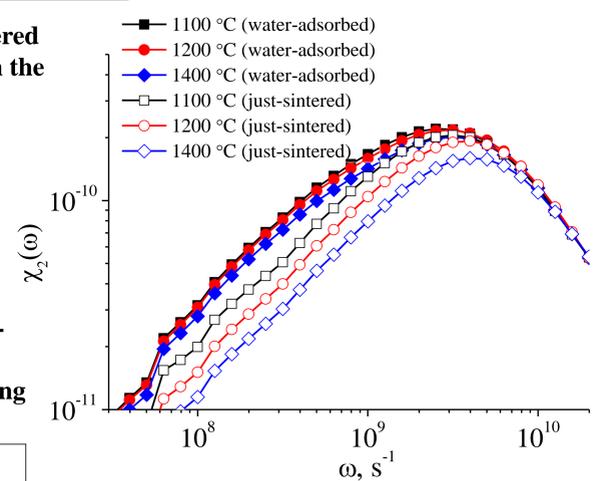## Modulated PEA kinetics of ceramics in the frequency domain
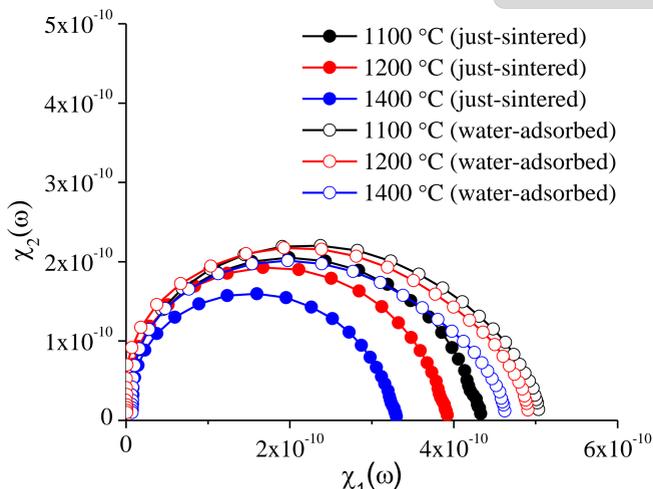
Complex diagram modulated PEA kinetics of ceramics in the frequency domain of just-sintered (close symbols) and water-adsorbed (open symbols) MgO-Al$_2$O$_3$ ceramics obtained at 1100, 1200 and 1400 ºC

Parameters of PEA response in frequency domain of the just-sintered MgO-Al$_2$O$_3$ ceramics obtained from position of large maximum on the spectra of imaginary part and from Debye law fitting

T_s, ºC	f_{max1}, GHz	τ_{max1}, ns	f_{D1}, GHz	τ_{D1}, ns
1100	0.501	0.318	0.459	0.347
1200	0.603	0.264	0.535	0.30
1400	0.645	0.247	0.602	0.265

Parameters of PEA response in the frequency domain of the water-adsorbed MgO-Al$_2$O$_3$ ceramics obtained from position of large maximum on the spectra of imaginary part and from Debye law fitting

T_s, ºC	$f_{max1,2}$, GHz	$\tau_{max1,2}$, ns	$I_{1,2}$	f_{max3}, MHz	τ_{max3}, ns	I_3
1100	0.45	0.357	0.823	80	2.0	0.177
1200	0.48	0.333	0.816	80	2.0	0.184
1400	0.48	0.333	0.860	59	2.7	0.140

Frequency dependencies of $\chi_2(\omega)$ for just-sintered (solid symbols) and water-adsorbed (open symbols) MgO-Al$_2$O$_3$ ceramics obtained at 1100, 1200 and 1400 ºC

Water adsorption by MgO-Al$_2$O$_3$ ceramics leads to significant increasing of amplitude of lower-frequency Debye type like relaxation component ($\tau_3 \sim 2$ ns) on modulated PEA spectra in comparison with as just-sintered samples. The kinetics of PEA in water-adsorbed MgO-Al$_2$O$_3$ ceramics in the frequency domain can be presented as the sum of two Debye type relaxation components with characteristic relaxation times of about 0.3 and 2 ns. No any evidences of deviation (spreading) the spectra from Debye type law have been observed within the range of experimental error. That indicates on no-correlative character of PEA relaxation in water-adsorbed MgO-Al$_2$O$_3$ ceramics via fast relaxation channels ($\tau_{1,2} = 1/\omega_{01,2}$, τ_3).