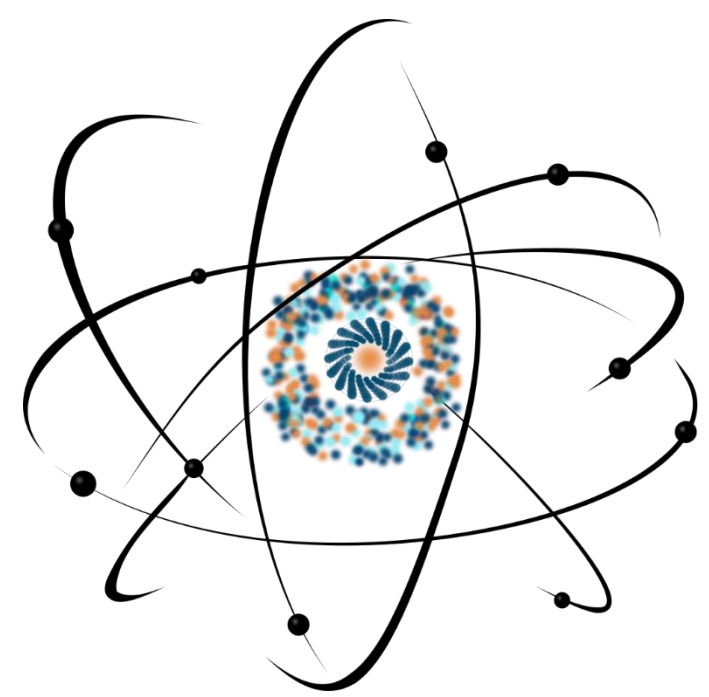


Exploring nanovoids in ceramic solids using positron-positronium trapping models



H. Klym^{1,2*}, A. Ingram³, N. Karpiuk¹

¹Lviv Polytechnic National University, Lviv, Ukraine

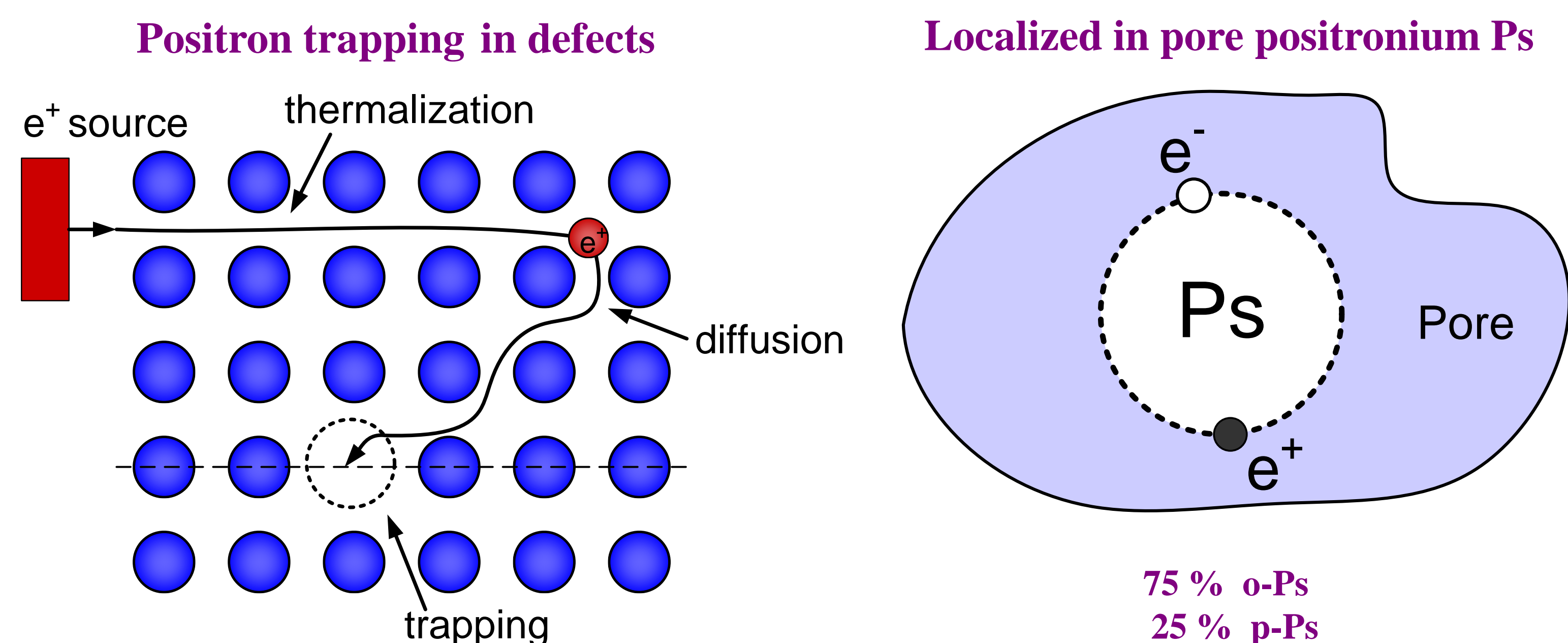
*klymha@yahoo.com, halyna.i.klym@lpnu.ua

²Ivan Franko National University of Lviv, Lviv, Ukraine

³Opole University of Technology, Opole, Poland

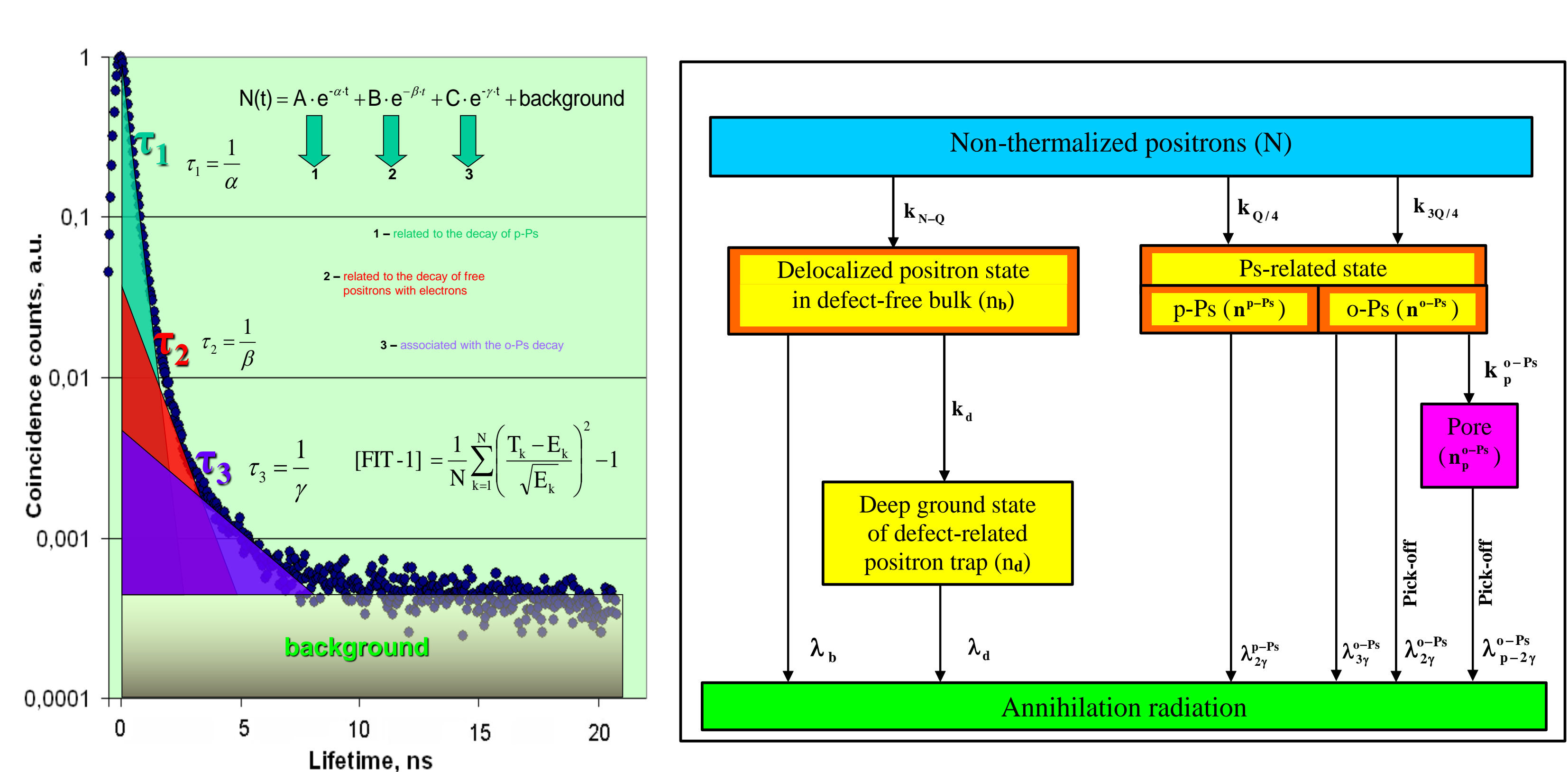
Herein we demonstrate the specifics of using positron annihilation lifetime spectroscopy (PALS) method for the study of free volume changes in functional ceramic materials. Choosing technological modification of MgAl₂O₄ spinel as an example, we show that for ceramics with well-developed porosity, free-volume defects facilitated positron trapping channels are enabled and ortho-positronium atoms decay may occur. Trapping in channels is described by two components and decay process by single or multiple components, depending on how well porosity is developed and on the experimental configuration. When using universal positron annihilation lifetime spectroscopy analysis, three components are the most suitable fit in case of MgAl₂O₄ ceramics. In the analysis of the second component, it is shown that technological modification (increasing sintering temperature) leads to volume shrinking and decreases the number of extended positron trapping defects near grain boundaries. This process is also accompanied by the decrease of the size of nanopores or nanovoids (described by the third component), while the overall number of nanopores is not affected. The universal approach to the analysis of positron annihilation lifetime spectra presented here can be applied to a wide range of functional materials with pronounced porosity.

EXPERIMENTAL: Positron Annihilation Lifetime (PAL) Spectroscopy

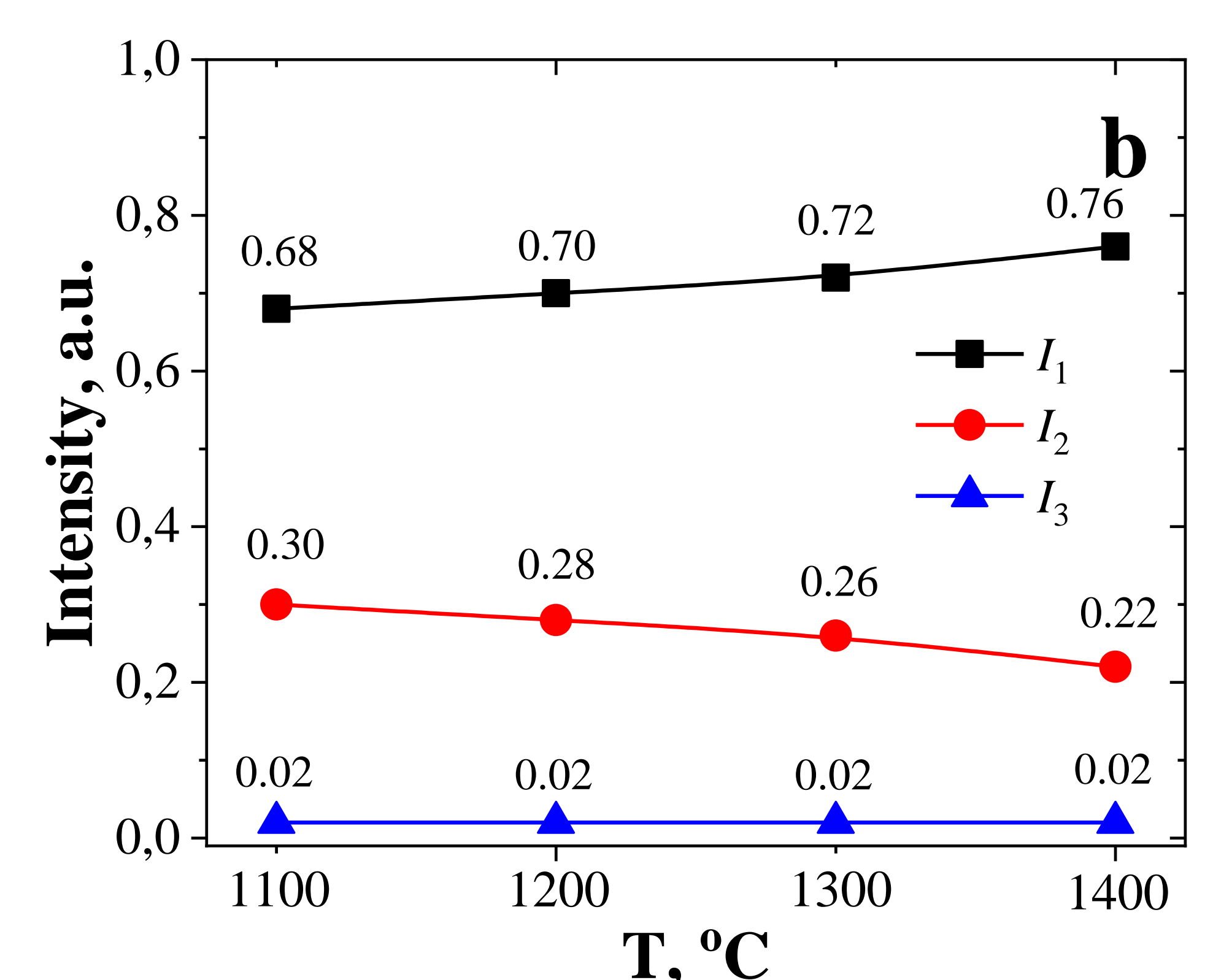
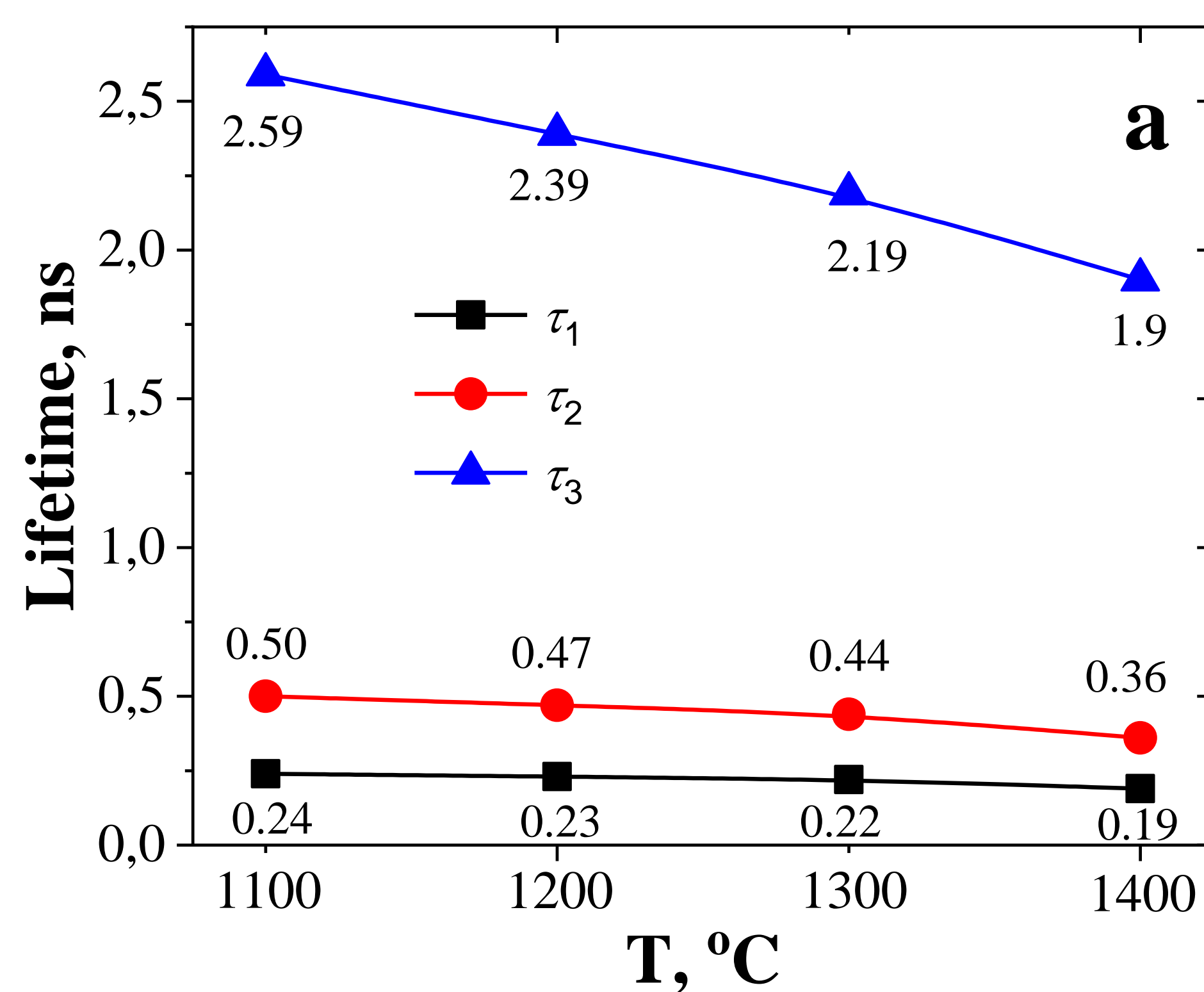
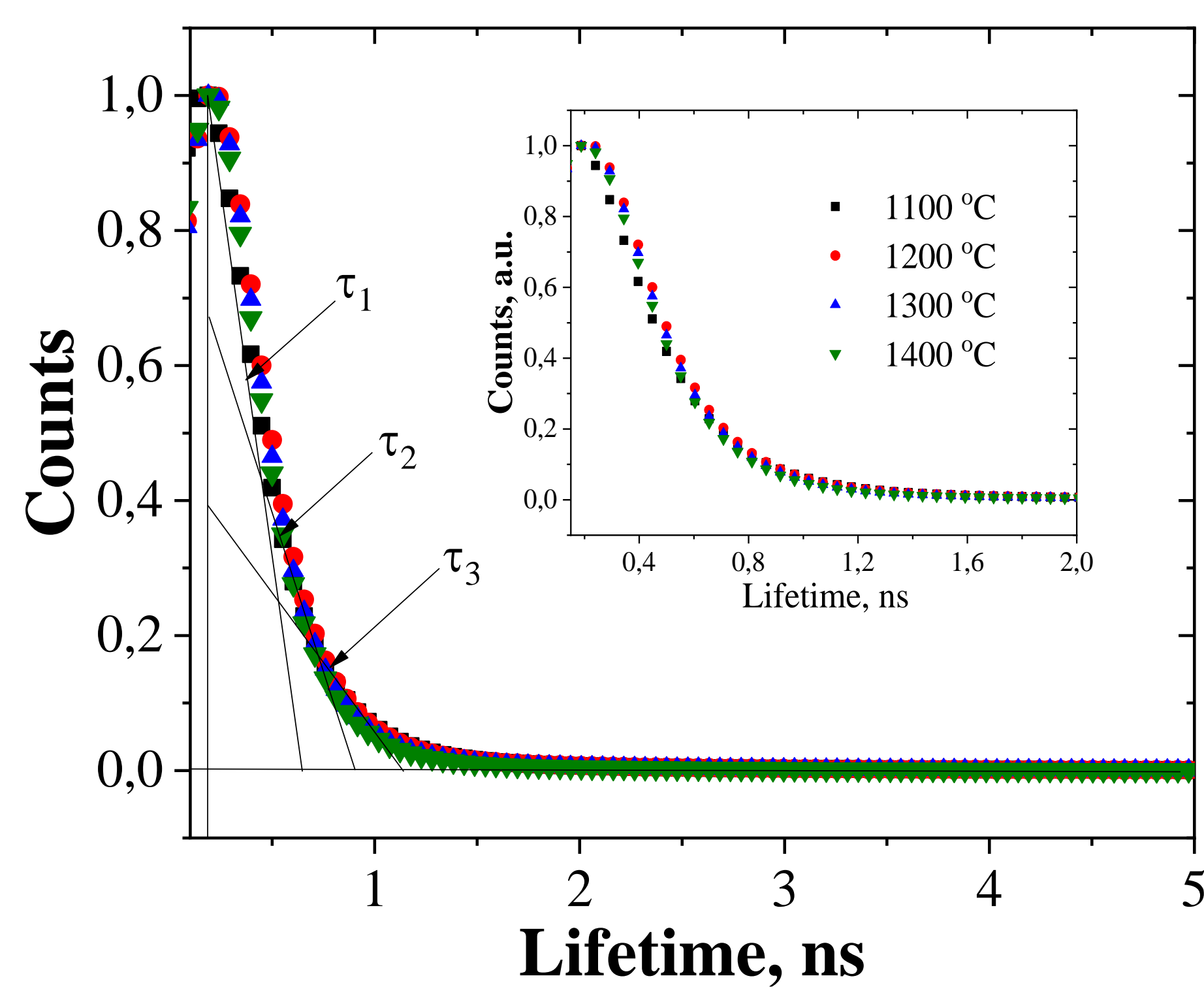


The PAL spectra were recorded with conventional fast-fast coincidence system (ORTEC) of 230 ps resolution (determined by ⁶⁰Co isotope measuring) at the temperature $T = 22$ °C and relative humidity $RH = 35$ %, provided by special climatic installation. The obtained results agreed well with each other within experimental uncertainties, being no more than ± 0.005 ns in lifetimes and ± 0.01 in component intensities. Each spectrum was measured with a channel width of 6.15 ps (the total number of channels was 8000) and contained at least $\sim 10^6$ coincidences in a total, which can be considered as conditions of normal PAL measurement statistics.

MATHEMATICAL TREATMENT of PAL DATA: LT computer program, 3-component fitting procedure



PAL RESULTS: Fitting parameters and positron trapping modes within 3-component fitting

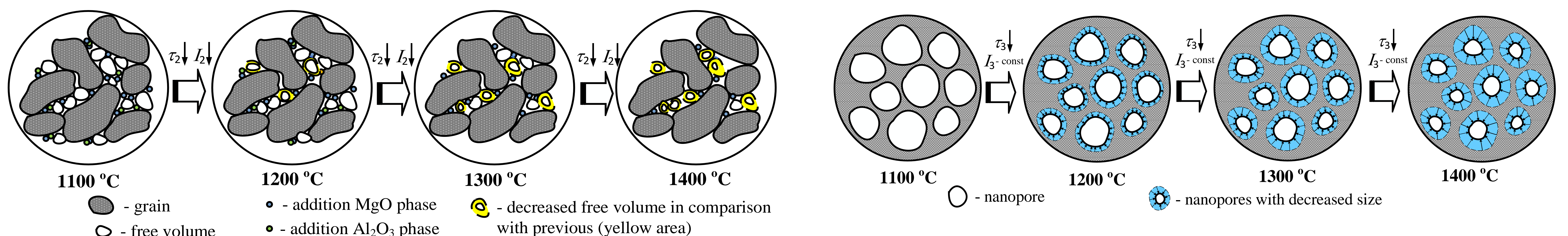


Normalized positron lifetime spectra for MgAl₂O₄ ceramics sintered at 1100–1400 °C during 2 hours with schematic illustration of tangents on each region at decomposition spectrum into three components.

Dependencies of lifetimes (a) and intensities (b) of PALS spectrum on the ceramics sintering temperature

For functional ceramic materials two PALS channels are enabled: positron trapping by extended free-volume defects (positron trapping sites) with short and average positron lifetimes (τ_1 and τ_2 , respectively) and the channel related to the decay of o-Ps atoms (including the “pick-off” process) with long lifetime τ_3 . In the frame of the proposed model [44], in MgAl₂O₄ ceramics the short positron lifetime (lifetime τ_1 and intensity I_1) reflects main microstructural features of the spinel with octahedral and tetrahedral vacancies, which are potential locations for positron trapping. Knowing lifetimes of this component one can estimate the sizes of voids formed by the principal phase in the material.

For MgAl₂O₄ ceramics obtained at 1100–1400 °C during 2 h, lifetime τ_1 of the first short component decrease slightly with increasing T_s , whereas intensity I_1 is increasing. Such changes speak in favor of ceramics quality increasing towards higher perfection level when using higher sintering temperatures. Lifetime of the second component τ_2 is related to the positron trapping in defect-related sites. As known from X-ray diffraction, MgAl₂O₄ ceramics contains different amounts of MgO/Al₂O₃ phases. These amounts decrease with increasing T_s . As confirmed by scanning electron microscopy studies, additional phases are irregularly distributed across the ceramics volume and are mainly localized near grain boundaries. Separated MgO and Al₂O₃ phases play a role of specific positron trapping centers in the ceramics free volume. Since ceramics obtained at lower temperatures include larger amounts of additional phases, positron trapping in such samples should be more pronounced. The third long component of PALS spectrum (the second channel of positron annihilation with lifetime τ_3 and intensity I_3) is connected to the decay of o-Ps atoms in nanopores and also to the “pick-off” annihilation process



Schematic depiction of the evolution of internal free volume defects at grain boundaries in MgAl₂O₄ ceramics

Diagram explaining the evolution of nanovoids in the internal structure of MgAl₂O₄ ceramics sintered at 1100–1400 °C during 2 hours.