# POSITRON LIFETIME DETERMINATION OF InP BY A HIGH RESOLUTION TIME SPECTROMETER*

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## ABSTRACT

Positron lifetime was measured on crystalline indium phosphide by a high resolution time spectrometer. By trapping model positron lifetime in bulk InP was estimated at 231.5±1.5 ps which was carefully compared with the experimental and the theoretical values known from the literature.

**Keywords:** Positron lifetime Semiconductor

## 1 INTRODUCTION

When energetic positrons reach the bulk of the sample material they will annihilate with electrons from the surrounding medium. According to Dirac's theory the average lifetime of positrons is

$$\tau = 1/\pi r_0^2 c n_e \tag{1}$$

here $r_0$ is the classical electron radius and $n_e$ is the electron density at the site of the positron. Thus a positron can serve as a test particle for the electron density of the medium. However, the electron density $n_e$ is enhanced from the equilibrium value in matter due to the Coulomb screening of the positron. Partically, because the resolving time of general time spectrometer is not enough good and an instrumental resolution function can never be exactly defined, they made the measurement of positron lifetime into a complicated problem, and different experiment values were obtained in different works. In the case of semiconductor these studies are more difficult. Bulk lifetime values of semiconductors always are higher than that of metal so that we can not easily differentiate the bulk lifetime of semiconductor from the vacancy lifetime of metal. In addition, the temperature dependence of the lifetime for semiconductors is more pronounced[1].

In this paper a major aim is to determine the lifetime in bulk indium phosphide (InP), which will be an essential parameter for studies of other systems in which InP

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is the main component[2] and for measurement of positron mobility in InP. A high resolution time spectrometer was employed and the resolution function was deduced from the lifetime spectrum of reference sample. Although there had been other work on the positron lifetime in InP, there is a considerable scatter of results. The results obtained in this paper were compared with other experimental and theoretical values of lifetime in InP. The vacancy-related defects in the specimen were analysed as well.

## 2 EXPERIMENTAL

Monocrystalline samples with a thickness of about 1 mm were cut from a large single crystal of P-type high resistance InP. Samples were fully annealed before the measurement. A conventional fast-slow coincidence system with $BaF_2$ detectors and the time resolution FHWM of 180 ps (Na-22 window by $^{60}Co$ source) was used (in Munich, Germany). The $1.776\times10^{11}$ Bq Na-22 source was contained between two 2 μm Ti foils which were sandwiched into two sample discs. In each lifetime spectrum $1\times10^{6}$ events were accumulated.

The time resolution function was determined with the PROMPTAN program from reference spectra measured for annealed stainless steel samples using the same source. It is possible to obtain a rather good initial estimate value of the resolution function. Then, the Gaussian parameters of resolution function were changed by small increments until the stainless steel lifetime extracted from POSITRONFIT program analyses is $106\pm0.4$ ps.

The spectra for InP were analysed with the POSITRONFIT program. In these analyses a correction was made for positrons annihilating in the source, 338.8 ps, 4.29 %. The source correction was determined from the reference spectra.

## 3 RESULTS AND DISCUSSION

Typical results after source correction are given in table 1. The presence of the $\tau_2$ component indicates that a fraction of positrons are trapped in defects before annihilation. The trapping rate $K$ and the intrinsic bulk lifetime $\tau_b$ can be calculated from the trapping model[3].

**Table 1**

**Positron lifetime parameters measured for InP**

| $\tau_1$/ps | $\tau_2$/ps | $I_1$/ % | $I_2$/ % | $10^7\times K/s^{-1}$ | $\tau_b$/ps |
|---|---|---|---|---|---|
| $227.1\pm1.1$ | $482.4\pm31.5$ | $96.45\pm1.27$ | $3.55\pm0.75$ | $8.3\pm1.8$ | $231.5\pm1.5$ |

The bulk lifetime obtained by experiment at room temperature is $231.5\pm1.5$ ps which agrees well with the experimental results given by S Dannefaer[4]. In table 2 the present result is compared with lifetimes for InP from literature. In Ref.[9], the authors deduced a semi-empirical relationship between the $e^+$ annihilation rates and the density of valence electrons in metals and semiconductors

$$\lambda^* = (\tau_b^{-1} - \lambda_\infty)/\lambda_\infty \tag{2}$$

Here making use of the theoretical result that $e^+$ lifetime in a electron gas cannot exceed the low-density limit of $\lambda_\infty^{-1} = 500$ ps. From systematic study, in the majority of elemental and compound semiconductors the dimensionless $e^+$ annihilation rates $\lambda^*$ are described by

$$\lambda^* = (11.1Z\, V_B/V_A)^{0.80} \tag{3}$$

where $Z$ denotes the number of conduction or valence electrons per atom, $V_A$ the atomic volume, and $V_B$ Bohr's volume. The bulk lifetime $\tau_b$ for InP is 242 ps with $Z=4$, $V_A/V_B=41$.

**Table 2**

**Bulk positron lifetime in InP**

| | Experimental | | | | | | Theoretical | | |
|---|---|---|---|---|---|---|---|---|---|
| $\tau_b$/ps | 232 | 235 | 246 | 244 | 242 | 240 | 242 | 246 | 237 |
| Reference | Present | [4] | [1] | [5] | [6, 7] | [8] | [9] | [10] | [10] |

Basing on the many-body theory for the screening of a positron in electron gas, the calculated positron bulk lifetimes are 246 ps according to the semiconductors model and 237 ps according to the insulator model respectively[10].

The parameters $\tau_1$, $\tau_2$, $I_1$ and $I_2$ determined by least squares fitting to the experimental lifetime spectrum varied significantly for different samples of InP but $\tau_b$ should nevertheless stay constant theoretically if the analysis was correct. However, $\tau_b$ is experimentally different for various samples of InP. There are two possible reasons for us to explain this discrepancy. Chang Tianbao *et al.*[11] found that the lifetime values of positron annihilation in some pure metals measured with the $BaF_2$ spectrometer are ~ 10 % smaller than the values measured with the plastic scintillator. Therefore the choice of scintillator will influence the positron lifetime values measured. On the other hand $\tau_b$ will be different for various doping types and depend on concentrations in the semiconductor samples. S.Dannefaer *et al.*[12] studied bulk lifetime with various doping conditions for gallium arsenide (GaAs) and found that there are the shallow positron trapping states associated with impurity atoms in GaAs. Positrons at the shallow trapping states have lifetimes which are very close to the bulk state within 10 ps. We think that it is possible to present similar states in InP. It is necessary to study the relation between these factors and bulk lifetime carefully.

The other important feature of the positron data is characteristic value of $\tau_2$.

According to the results calculated by Puska *et al.*[10], the lifetime in InP are 295 ps for trapped at In vacancies, 273 ps for trapped at P vacancies and 340 ps for trapped at nearest-neighbor divacancies. Our value, $\tau_2 = 482$ ps, from the present work is significantly larger than that above. Beling *et al.*[8] pointed out that it indicated the quadrivacancies in InP. However, a precise identification is difficult because of the possible influence of impurities[13]. The properties of these vacancies need studying further.

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