Dynamics of T-Site Muonium States in Gallium Phosphide

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Muon spin resonance results on semi-insulating GaP suggest the presence of two separate diamagnetic states above roughly 400 K. The diamagnetic RF-\(\mu\)SR resonance amplitude increases starting at that point, then decreases above 550 K, consistent with two signals displaying different dynamics. The second state, present from \(\sim 400\) to \(630\) K, is assigned to the negative ion, Mu\textsuperscript{t}, expected to reside in the tetrahedral (T) site with Ga near neighbours. The single state at lower temperatures is assigned to a mobile Mu\textsuperscript{+}, claimed \cite{1} to hop among the T-sites with phosphorous neighbours above 300 K, even though the stable site for a stationary Mu\textsuperscript{+} is bond-centered. Interactions between mobile Mu centers and Zn acceptors were reported \cite{2} for p-type GaP, and assigned to charge exchange between Mu\textsuperscript{0} and Zn\textsuperscript{0} below \(\sim 100\) K and to Coulomb capture of Mu\textsuperscript{T+} by Zn\textsuperscript{1} above 400 K. Here we report in detail on the motional dynamics of Mu\textsuperscript{t} and the ionization processes related to the Mu\textsuperscript{T} acceptor state. We obtain an energy of \(\sim 0.82\) eV from the growth step in the RF data for the standard Mu\textsuperscript{T} acceptor-related hole ionization. The loss of the Mu\textsuperscript{t} RF-component yields an energy of \(\sim 1.7\) eV, which is assigned to thermal promotion of an electron from Mu\textsuperscript{t} to the conduction band, \textit{i.e.} ionization of Mu\textsuperscript{t}. These two results place the Mu\textsuperscript{T} acceptor level with respect to the valence and conduction band edges, respectively. The difference in these placements represents the Coulomb energy for Mu\textsuperscript{t} in the positively charged T\textsubscript{Ga} region. Low-field spin precession and zero-field depolarization data on n-type GaP in the \(10^{16}\) to \(10^{18}\) cm\textsuperscript{3} concentration range show a peak in diamagnetic fraction below 300 K and a roughly linear increase in the net diamagnetic signal above that, nearing the full muon fraction only above 900 K. Both regions show characteristics of Mu\textsuperscript{t}. The onset of Mu\textsuperscript{t} motion above 500 K overlaps with the loss an electron, making a clean separation of these processes in the depolarization data marginal; however, initial results give a barrier of nearly 9 eV. Additionally, a Mu\textsuperscript{T} charge cycle sets in above the electron loss transition; however, it is not obvious at present whether this represents a +/0 or a 0/t cycle, or precisely which transition processes are active in n-type samples at the highest temperatures.