# Thermal Ionization of Bond-centred Muonium in Diamond

M. Madhuku[1,3], D. Gxawu[2], S. H. Connell, I. Z. Machi[3], J. M. Keartland[1], S. F. J. Cox[4] and P. J. C. King[4]

[1] *School of Physics, University of the Witwatersrand, Johannesburg 2050, South Africa*
[2] *Physics Department, Durban University of Technology, Durban 4001, South Africa*
[3] *iThemba LABS (Gauteng), Private Bag 11, Wits 2050, South Africa*
[4] *ISIS Facility, Rutherford Appleton Laboratory, Chilton, Oxfordshire, United Kingdom*

A positive muon implanted into an insulator or semiconductor often binds an electron to form muonium ($\mu^+e^- \equiv$ Mu), a paramagnetic atom electronically similar to hydrogen. The thermal ionization of bond-centred muonium ($Mu_{BC}$) in natural type Ia single crystal diamond was studied using the longitudinal magnetic field muon spin relaxation (LF-$\mu$SR) and the transverse field muon spin rotation (TF-$\mu$SR) techniques. The optical characterization methods revealed the presence of A, B, P1, and P2 centres in the samples. The $Mu_{BC}$ state in diamond is easily observed and there is a very good correlation between theoretical and experimental hyperfine parameters [1]. Curiously, despite its predicted stability, the bond-centred hydrogen state has not yet been observed in diamond. Following the discovery of hydrogen dopant states in certain wide band gap metal oxides, and the possibility of hydrogen related molecular dopants in diamond, the study of hydrogen in diamond is important. Although it is evident from its hyperfine parameters that $Mu_{BC}$ is not a shallow donor, the question still arises as to where the $Mu_{BC}$ state in diamond might lie in the band gap. Accordingly, measurements of high temperature stability of $Mu_{BC}$ have been performed in a search for its possible ionization. The experimental results showed that $Mu_{BC}$ in diamond ionizes around 1000 K with activation energy varying between 0.60 and 1.80 eV depending on the theoretical model used. This is the first time that the ionisation energy of bond-centred muonium in diamond has been determined. The results are consistent with such an ionisation, as the disappearance of $Mu_{BC}$ is correlated with the increase in the population of the diamagnetic, $\mu^+$, species. Furthermore, it is the first time that the $Mu_T \rightarrow Mu_{BC}$ transition has been observed in longitudinal field.

[1] J. W. Schneider et al., Phys. Rev. Lett. 71/4 (1993) 557.