Transverse-field (TF) and longitudinal-field (LF) \( \mu^+SR \) measurements have been made on conducting GaAs:Si (n-type \( \approx 10^{18} \) cm\(^{-3} \)) and GaAs:Zn (p-type \( \approx 10^{18} \) cm\(^{-3} \)) from 20 mK to 200 K. At low temperatures in GaAs:Si, the frequency spectra show a large diamagnetic signal as well as broad lines due to bond-centered muonium (Mu\(_{BC}\)). This broadening is attributed to spin exchange interactions with charge carriers in impurity bands. Only the diamagnetic signal is observed in GaAs:Zn. The field dependence of the TF diamagnetic relaxation rate at 5 K can be explained by the combined electric quadrupolar and Zeeman interaction between the muon and the surrounding nuclei and the temperature scan at TF=1.5 T indicates that the mechanisms responsible for the broadening are temperature independent. The candidates for the diamagnetic species are discussed in view of these results.

GaAs is the most well-studied III-V compound semiconductor. The majority of previous \( \mu^+SR \) work, however, has been restricted to high resistivity samples where there are a negligible number of conducting electrons or holes at low temperatures. If these samples are doped with a sufficient number of impurities, an insulator to metal transition will occur such that they conduct even at temperatures much below the ionization temperature of the impurities. Furthermore, the Fermi level is moved to the extreme edges of the band gap and can have a strong influence on the relative stability of the various muonium charge states.

In lightly doped GaAs, two neutral paramagnetic centers Mu\(_T\) and Mu\(_{BC}\) have been previously observed. Mu\(_T\) (called normal muonium) has an isotropic hyperfine parameter and appears to be moving rapidly [1] while Mu\(_{BC}\) (called anomalous muonium or Mu\(*\)) is located in a relaxed Ga-As bond [2]. The diamagnetic center Mu\(_D\) that is observed in Group 4 semiconductors such as Si and Ge is not seen. The conventional assignment for Mu\(_D\) is Mu\(^+\) although Mu\(^-\) cannot be ruled out. In heavily doped samples, another possibility for Mu\(_D\) is the muon-impurity complex, analogous to
In this paper, we present measurements on GaAs heavily doped with Zn (p-type) and Si (n-type) with longitudinal-field (LF) and transverse-field (TF) \( \mu \)SR. The experiment was performed in a He gas flow cryostat (TF measurements) on the M20 beamline and the dilution refrigerator (LF measurements) on the M15 beamline at TRIUMF with a positive muon beam of momentum \( \approx 28.6 \text{ MeV/c} \). The samples, grown by the Liquid Encapsulated Czochralski Method by Laser Diode Inc., had an area \( \approx 16 \text{ cm}^2 \) and are on the metallic side of the metal-insulator transition. The n-type GaAs:Si sample was doped at a level of \( 2.5-5 \times 10^{18} \text{ cm}^{-3} \) and the p-type GaAs:Zn sample was doped at a level of \( 2.8 \times 10^{19} \text{ cm}^{-3} \). In both samples, the \( <100> \) crystalline axis was parallel to the applied magnetic field \( \mathbf{B} \). LF scans were made in GaAs:Si in the range 20 mK to 5 K. A transverse field (TF) scan at 5 K and a temperature scan at TF=1.5 T from 5 K to 200 K were also made in both samples.

At low temperatures, the TF frequency spectra in GaAs:Si, an example of which is shown in Fig. 1a, show a large diamagnetic signal as well as broad lines due to \( \text{Mu}_{BC} \) which were not observable above \( \approx 20 \text{ K} \). Although a strong diamagnetic signal was also seen in GaAs:Zn in TF, no \( \text{Mu}_{BC} \) signatures could be detected. \( \text{Mu}_T \) was not directly observed in either sample.

the "passivated" centers observed for hydrogen in GaAs and other covalent semiconductors [3].

Fig. 1. (a) \( \mu \)SR frequency spectrum in GaAs:Si at 5 K with TF = 1.5 T applied along a \( <100> \) axis; \( \nu_{12}^* \) and \( \nu_{34}^* \) are due to \( \text{Mu}_{BC} \) and \( \nu_d \) labels the strong diamagnetic line. (b) \( G_z(t) \) in GaAs:Si with LF of 75 mT along a \( <100> \) axis at 4 K. Only the relaxing component is shown. There is a large non-relaxing component also present. Similar behavior was observed down to 20 mK, the lowest temperature measured in LF.