NMR Measurements of MAX Compounds

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Introduction

Magnetism in MAX compounds ($M_{n+1}AX_n$, where M is a transition metal, A is an A-group element, X = C or N, and n varies from 1-3) is poorly explored. NMR is a powerful tool for studying the nature of long-range magnetic order through the measurement of the hyperfine field in this system. Using the spin echo technique, it is possible to extract the RF enhancement factor η, which characterizes the nature of the magnetic state due to the effects of the domain walls [1],[2]. The NMR lineshapes are sensitive to phase transitions to a magnetic state, and also to the exact nature of this state. Long range magnetic order has been measured by Neutron Powder Diffraction (NPD) in Ge based Mn doped MAX compounds [3]. In this report, we outline the preliminary results of NMR and magnetization measurements that followed the initial NPD measurements.

Experimental

Frequency and field-swept NMR measurements were done on various MAX compound powder samples, using several NMR probes, in fields up to 17T, in the Condensed Matter NMR lab, and in temperatures down to 100mK using the milliKelvin facility at NHMFL. In addition, magnetization measurements were performed, using the Tunnel Diode Oscillator (TDO), down to a temperature of 2K, and up to fields of 9T.

Results and Discussion

Typical NMR results for the Ge based MAX compounds are shown in **Fig.#1**, where a very broad NMR signal is seen, and is attributed to ordered ^{55}Mn atoms. These measurements have also shown peculiar behavior above 4T, as shown in **Fig.#2**. In addition, TDO measurements in $(Cr_{0.96}Mn_{0.04})_2GeC$ compound, show a significant change in magnetization near zero field, indicating the existence of long range magnetic order at zero field. In addition, the enhancement factor η was calculated, based on a reference ^{1}H signal measured at 5.17T (not shown). This quantity distinguishes between Ferromagnetic (FM) and Anti-Ferromagnetic (AFM) states. For values below η < 1000, the magnetic state is in an AFM state, and for η > 1000, FM state. For $(Cr_{0.96}Mn_{0.04})_2GeC$ compound, at 220MHz and T= 50K, we found η ~ 80 - 120, hence pointing to the existence of an AFM state.

Conclusions

NMR and magnetization measurements have been performed for various Mn doped MAX compounds. A very wide NMR line, at zero field, attributed to ^{55}Mn, was observed, for both Ga and Ge based compounds. Also, a significant increase in NMR signal for high fields (above 4T) was measured for both compound families. All measurements point to the existence of long range magnetic order.

Acknowledgements

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References

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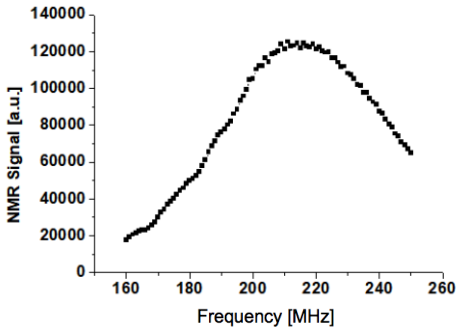

Fig. 1 NMR frequency scan of $(Cr_{0.96}Mn_{0.04})_2GeC$ compound, at a temperature of 1.6K and at 0T.

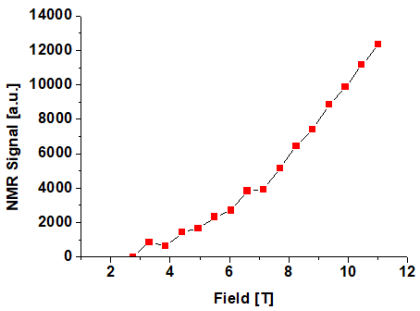

Fig. 2 NMR field scan of $(Cr_{0.96}Mn_{0.04})_2GeC$ compound, at a frequency of 96MHz, and at a temperature of 50K.