Magnetic properties of diluted magnetic semiconductor $Ge_{1-x-y}(Si_xMn_y)Te$ crystals

Sana Zakar[a], V.E. Slynko[b], Lukasz Kilanski

[a]*Institute of Physics of the Polish Academy of Sciences, al. Lotnikow 32/46, 02-668 Warsaw, Poland*

[b]Institute of Materials Science Problems, Ukrainian Academy of Sciences, Wilde Str., 58001 Chernivtsi, Ukraine

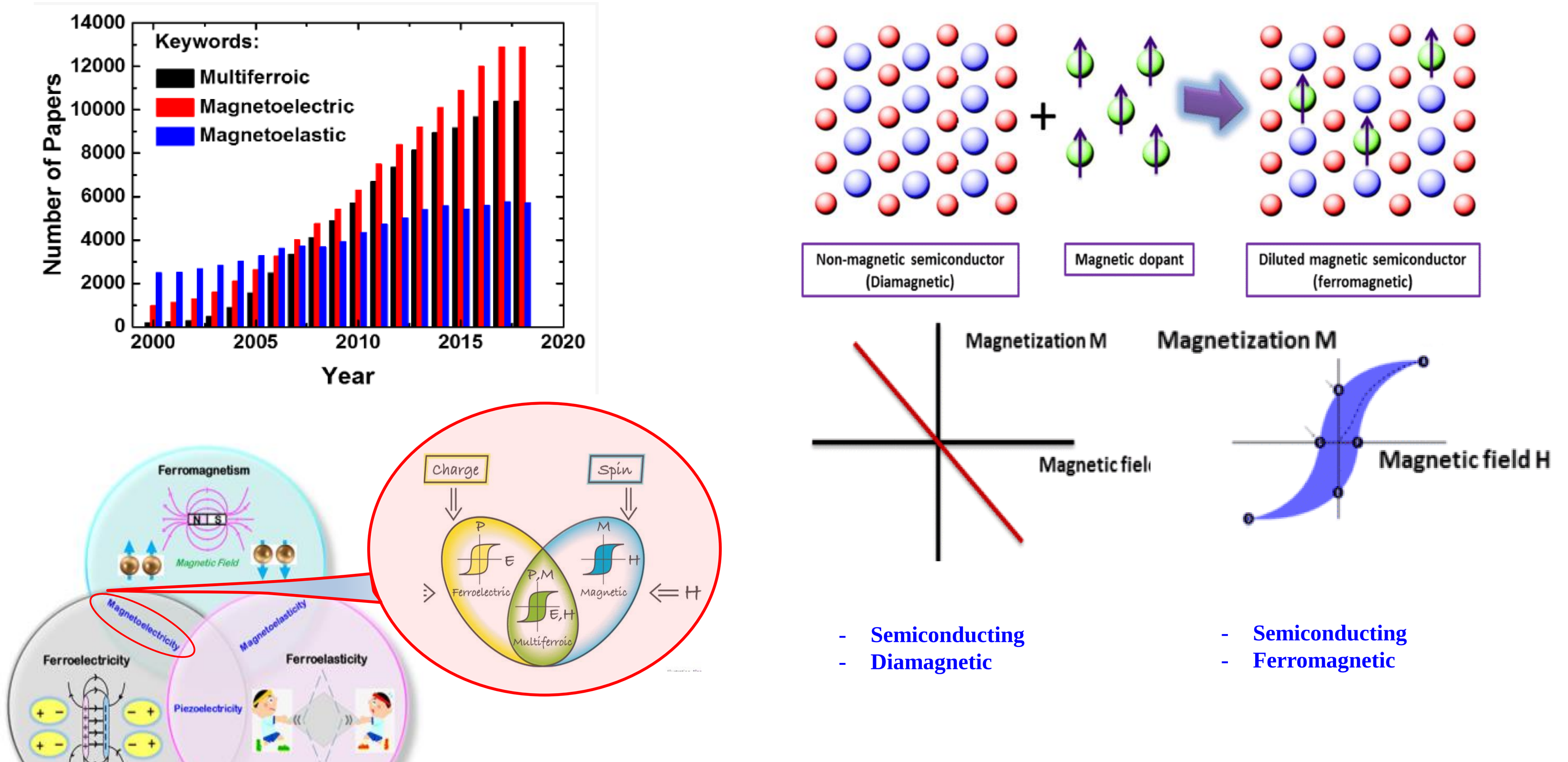
Correspondence to: sanaz@ifpan.edu.pl

Abstract

IV-VI materials doped with magnetic impurities hold potential for spintronic applications particularly by integrating the memory component within the semiconducting matrix. This works intends to investigate the carrier mediated magnetic interactions in GeTe lattice alloyed with Mn ions. We present $Ge_{1-x-y}Si_xMn_yTe$ bulk crystals by altering their chemical composition in the range $0.056 \leq x \leq 0.10$ and $0.0036 \leq y \leq 0.046$. The magnetic phase transition temperature rises from T_C = 25 K to about 160 K for the highest impurity level. The analysis of inverse of susceptibility with modified Curie-Weiss law finds ferromagnetic-like interaction in the alloys. The magnetically glassy samples were interpreted with frequency dependent susceptibility. This identified scaling parameter, R = 0.2 - 0.6 which indicate the formation of clusters in the glassy samples. Finally, the high field magnetization data has been used to calculate the number of active magnetic ions in semiconductor matrix.

Introduction and Motivation

Why Multiferroics

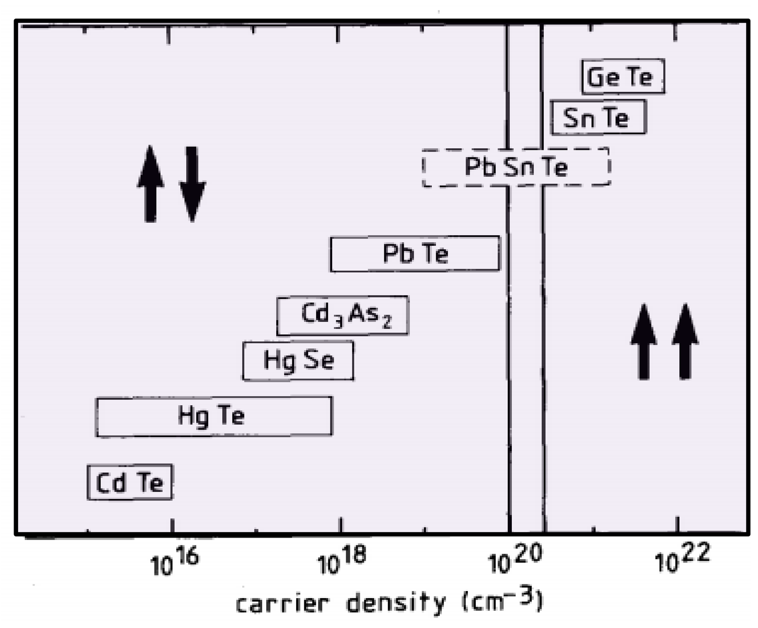


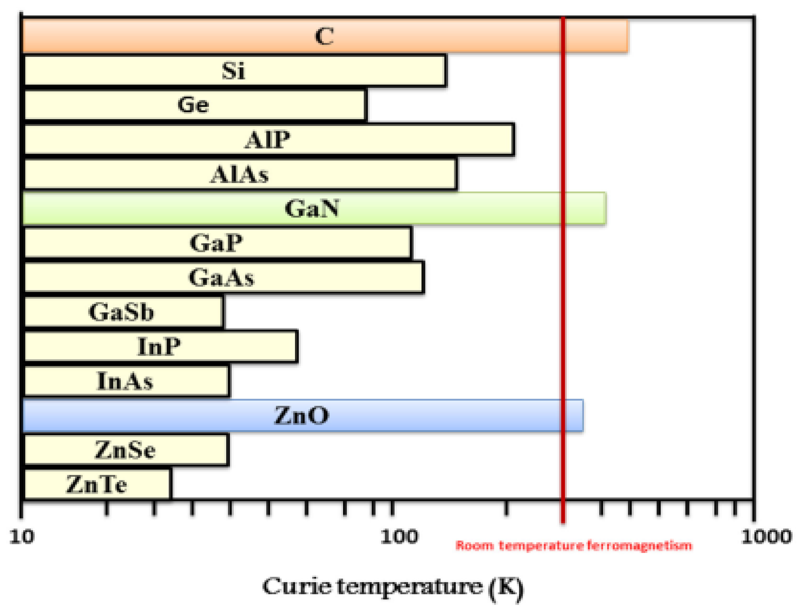
[1] W.J.M. de Jonge et al., *Journal of Magnetism and Magnetic Materials*, **100**, 322-345 (1991).

[2] Dietl, T., et al.,*Science*. **287**, 1019–1022 (2000).

Why IV-VI semiconductors

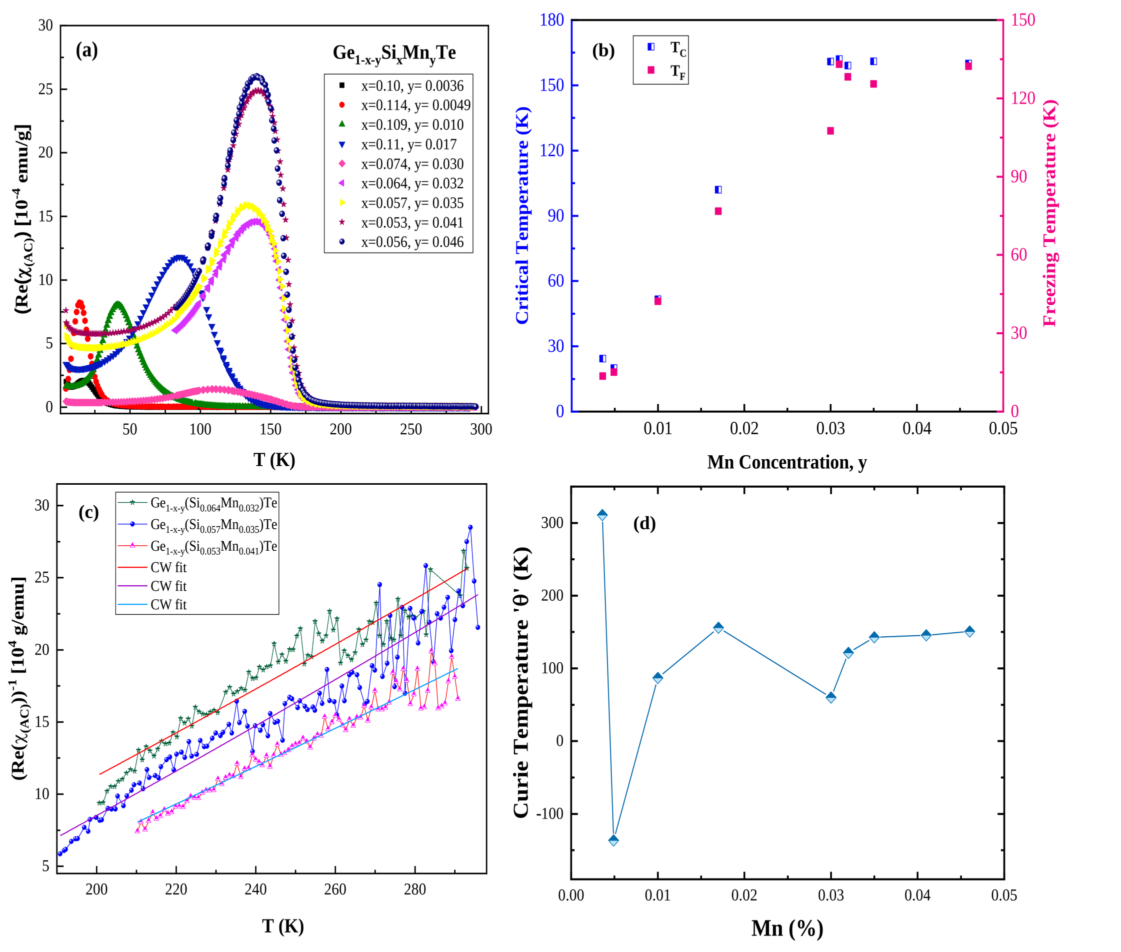
- Magnetic ion concentration
- Magnetic coupling strength
- Curie temperature
- Tailoring properties



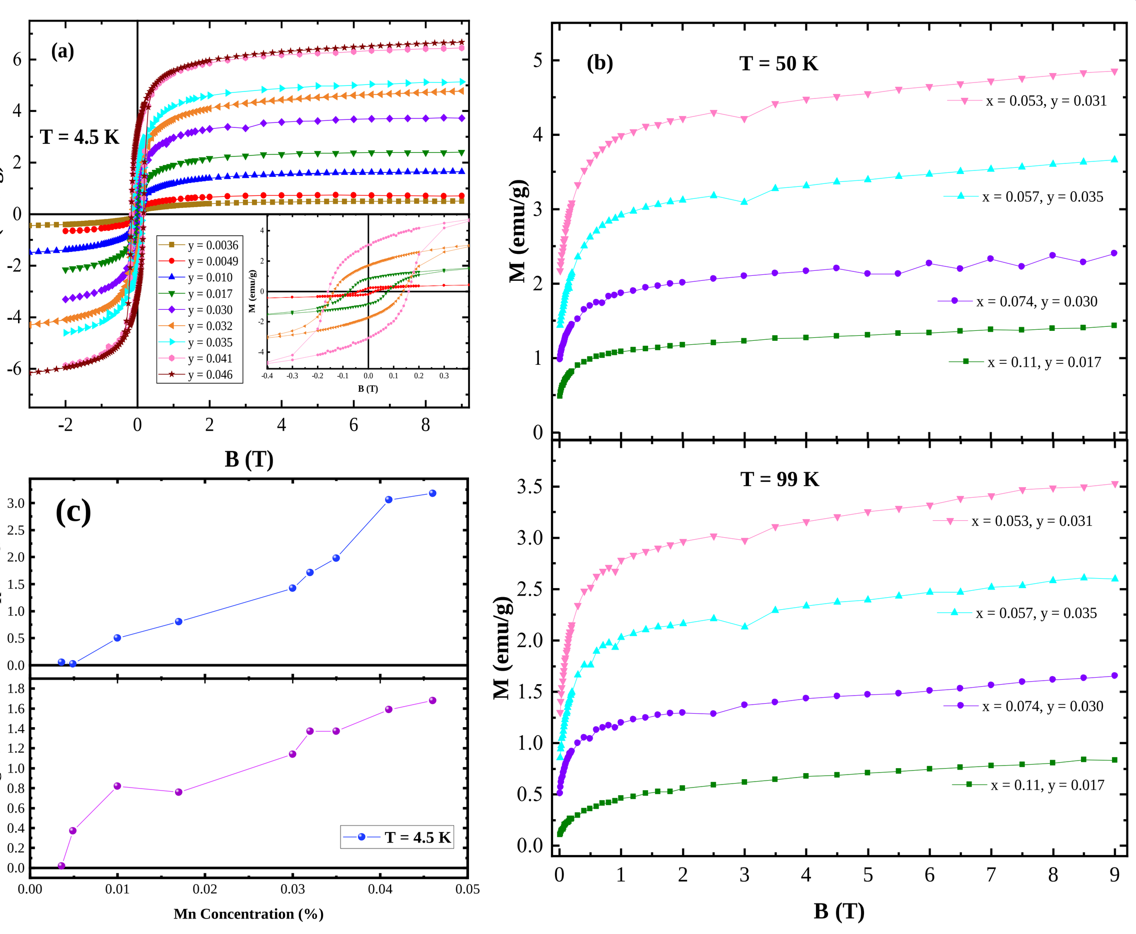


[2] Dietl, T., et al.,*Science*. **287**, 1019–1022 (2000).

Results and Discussion



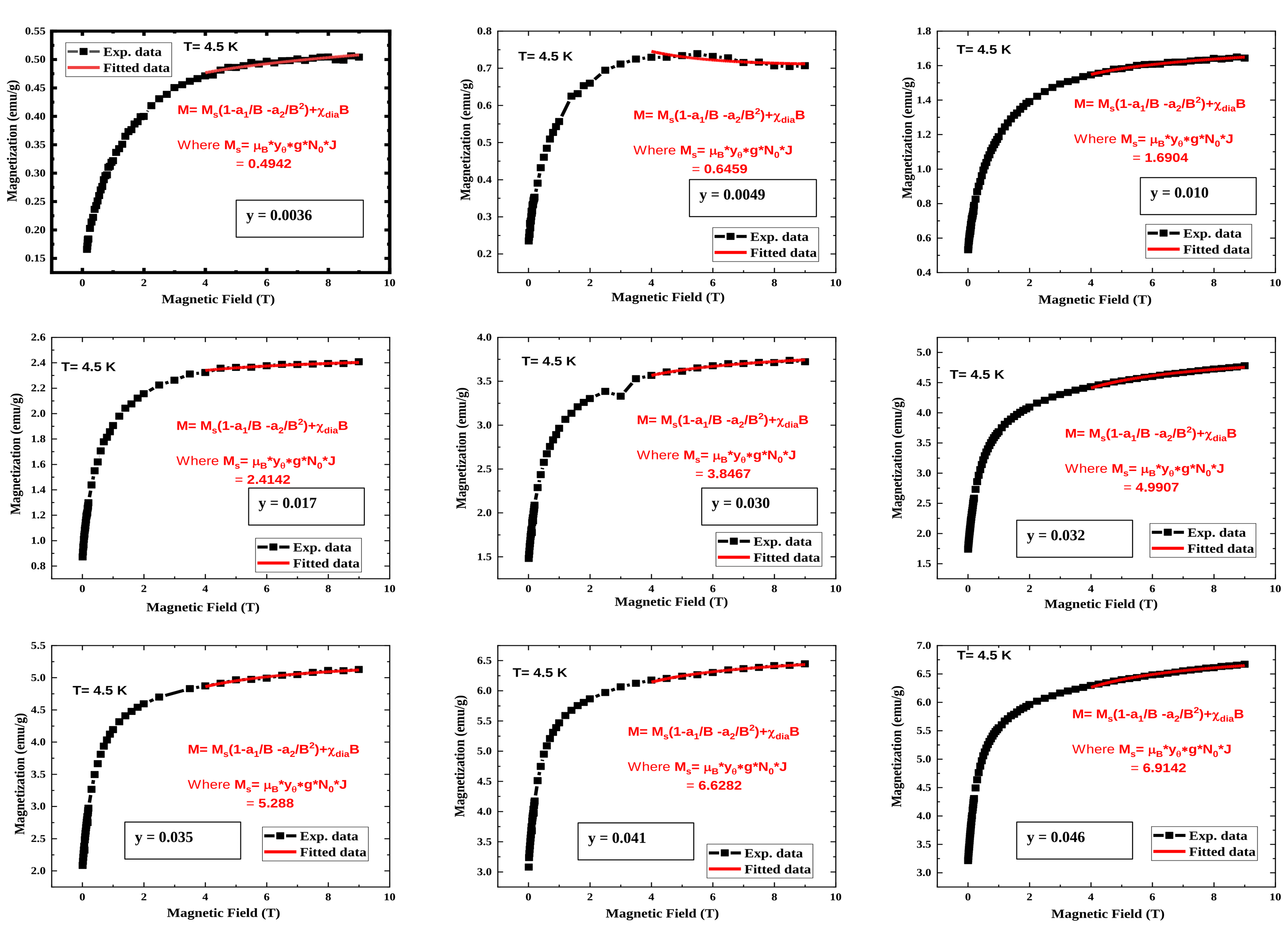
(a) Temperature dependent magnetic susceptibility $Re(\chi_{AC})$ of $Ge_{1-x-y}Si_xMn_yTe$, (b) Critical and freezing temperature as a function of Mn concentration, (c) Curie_Weiss fitiing in paramagnetic regime (d) Curie Temperature vs Mn concentration



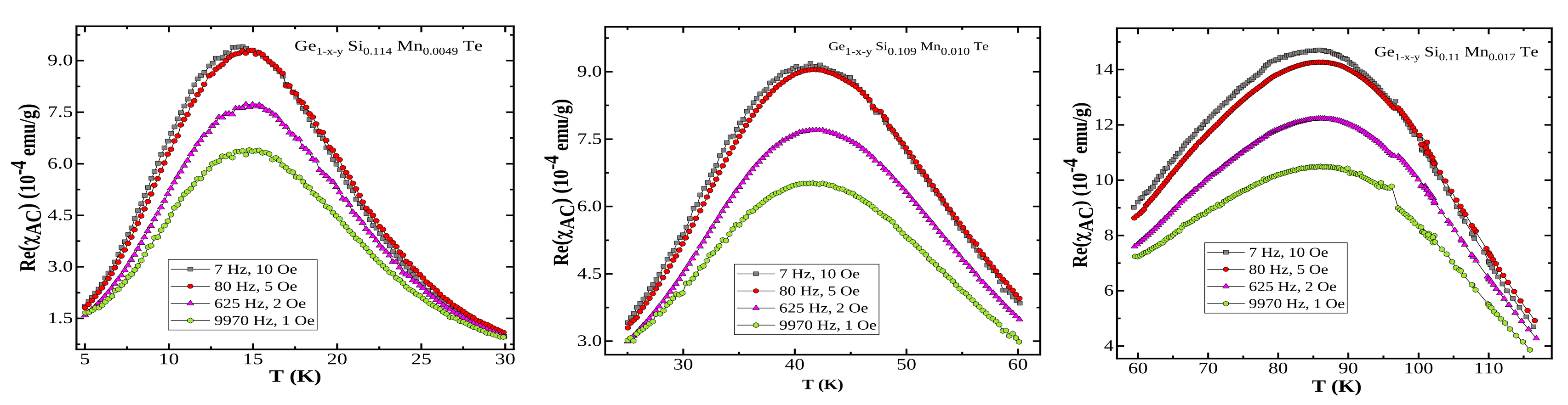
Magnetization as a function of magnetic field at different temperatures for different chemical compositions

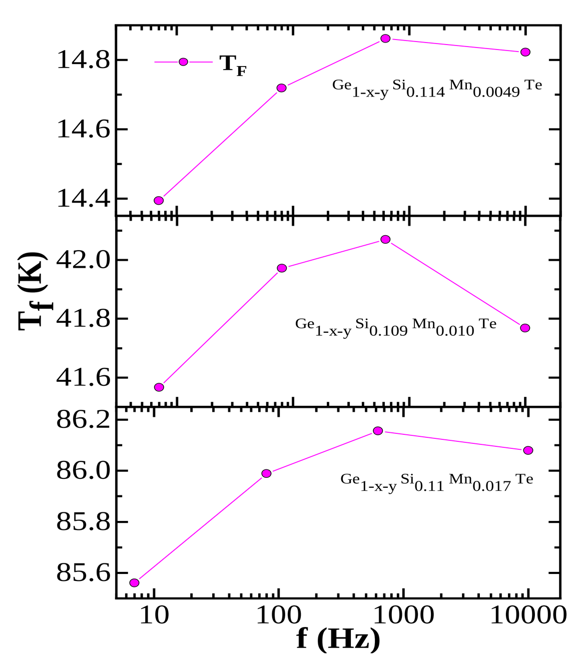
x	y	y_θ	Θ [K]	M_R [emu/g] T=4.5K	H_C [T] T= 4.5 K	$M_{S\text{-}exp}$ [emu/g] T=4.5K	$M_{S\text{-}th}$ [emu/g] T =4.5K
0.10	0.003	0.001	43.5 ± 1.3	0.05	0.2	0.4942	0.5139
0.114	0.0049	0.002	76.9 ± 5.3	0.2	0.3	0.6459	0.7018
0.109	0.010	0.005	112.8 ± 15.6	0.5	0.8	1.6904	1.4313
0.11	0.017	0.007	139.6 ± 0.2	0.8	0.7	2.4142	2.4353
0.074	0.030	0.010	149.8 ± 0.3	1.4	1.1	3.8467	4.2676
0.064	0.032	0.012	170.2 ± 3.5	1.7	1.3	4.99	4.5426
0.057	0.035	0.013	171 ± 1.3	2.0	1.3	5.2886	4.9620
0.053	0.041	0.019	172.8 ± 0.5	3.0	1.5	6.6282	5.8104
0.056	0.046	0.018	174.9 ± 0.7	3.1	1.6	6.9146	6.5264

Si content x, Mn content y, effective manganese content y_θ Curie-Weiss temperature Θ, remanence magnetization M_R, Coercive field H_C and magnetization saturation M_S calculated at temperature T = 4.5 K.



Magnetization measurement for different Mn content at T = 4.5 K and red lines represents a fitting of scaling approach law at high-field experimental data.





Si (x)	Mn (y)	T_{f1} [K] 07 Hz	T_{f2} [K] 80 Hz	T_{f3} [K] 625 Hz	T_{f4} [K] 9970 Hz	(R) T_{f1}-T_{f2}	(R) T_{f1}-T_{f3}	(R) T_{f1}-T_{f4}	(R) T_{f2}-T_{f3}	(R) T_{f2}-T_{f4}	(R) T_{f3}-T_{f4}
0.114	0.0049	14.39	14.72	14.86	14.82	0.33	0.47	0.43	0.14	0.1	-0.04
0.109	0.010	41.57	41.97	42.069	41.77	0.4	0.499	0.2	0.099	-0.2	-0.299
0.11	0.017	85.56	85.99	86.16	86.079	0.43	0.6	0.519	0.17	0.089	-0.081

Magnetic susceptibility with temperature measured for different ac magnetic field frequencies and freezing temperature T_F for different frequencies.

Conclusion

In conclusion, we have investigated the magnetic properties of a bulk $Ge_{1-x-y}Si_xMn_yTe$ crystal with a different chemical composition of Mn and Si. The crystal has been examined by temperature dependent magnetic susceptibility and magnetization measurements. Obtained results reveal the transition from paramagnet to ferromagnetic like ordering. The modified Curie-Weiss fitting done in paramagnetic region for analyzing the magnetic ordering and calculate Curie constant and Curie-Weiss temperature. . The transition state has further been analyzed by frequency dependent susceptibility measurements. Also, the *M(H)* curves having low coercive field attributes the existence of ferromagnetic state and magnetization saturation was estimated by fitting the phenomenological scaling approach law. The results shows that magnetic saturation *Ms* values are greatly influenced by changing/increasing the magnetic ion Mn concentration.