Supplementary information

Colossal negative magnetoresistance from hopping in insulating ferromagnetic semiconductors

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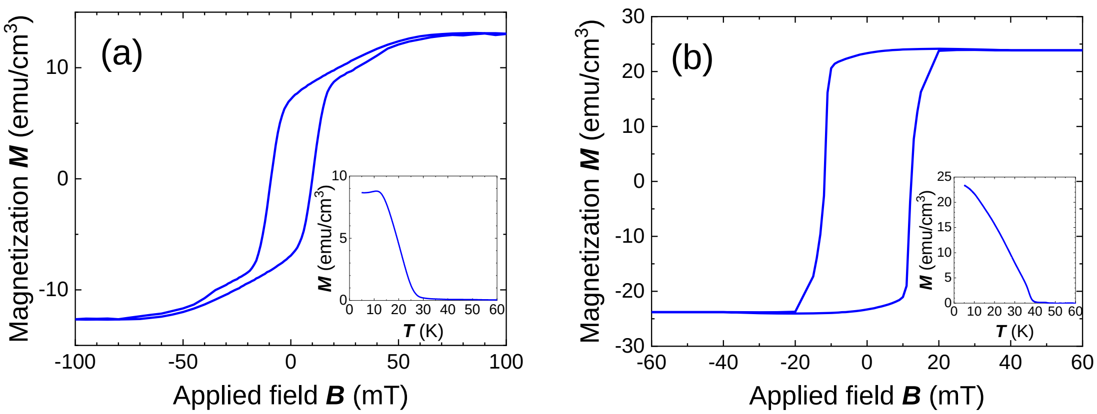

Fig. S1 Hysteresis loops measured at T = 5 K with magnetic field applied along out-of-plane [001] axis for two $Ga_{1-x}Mn_xAs_{0.79}P_{0.21}$ samples with Mn concentrations x of (a) 4% and (b) 6%, respectively. Inset: Corresponding temperature dependences of magnetization measured along out-of-plane [001] axis for each sample.

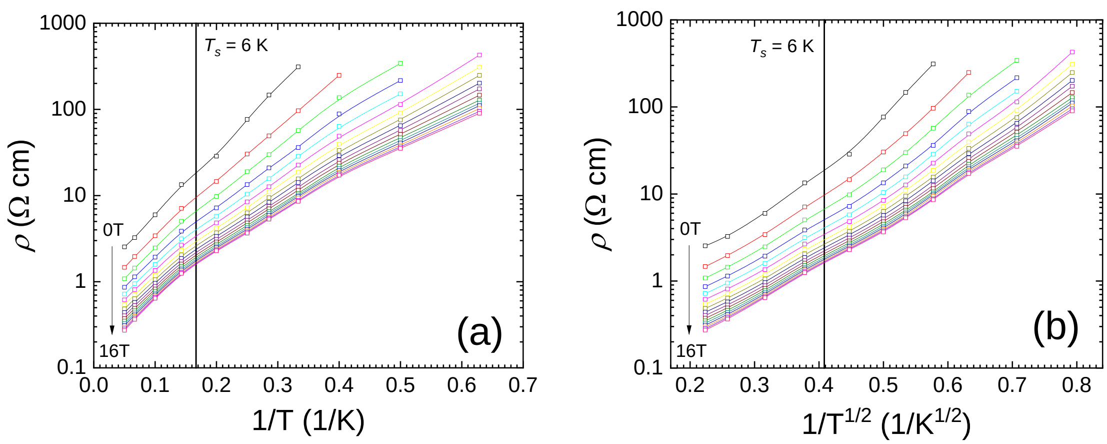

Fig. S2 Resistivity measured at various temperatures with magnetic field applied along out-of-plane [001] axis for $Ga_{0.96}Mn_{0.04}As_{0.79}P_{0.21}$ sample. (a) Scaling of resistivity versus $1/T$ at different magnetic fields. (b) Scaling of resistivity versus $1/T^{1/2}$ at different magnetic fields.

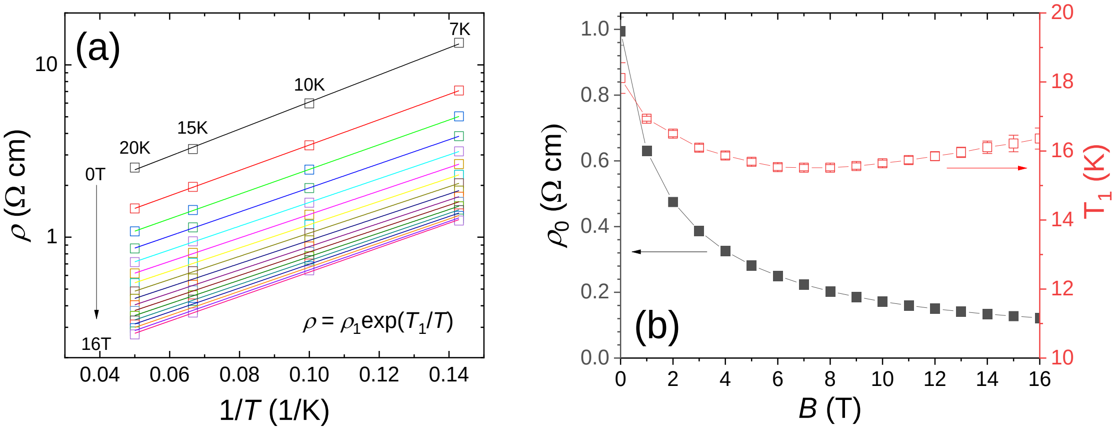

Fig. S3 (a) Scaling of resistivity versus 1/T at different magnetic fields for higher temperatures for $Ga_{0.96}Mn_{0.04}As_{0.79}P_{0.21}$ sample. The curves are fits of Eq. (1). (b) Field dependences of fitting parameters ρ_1 and T_1.

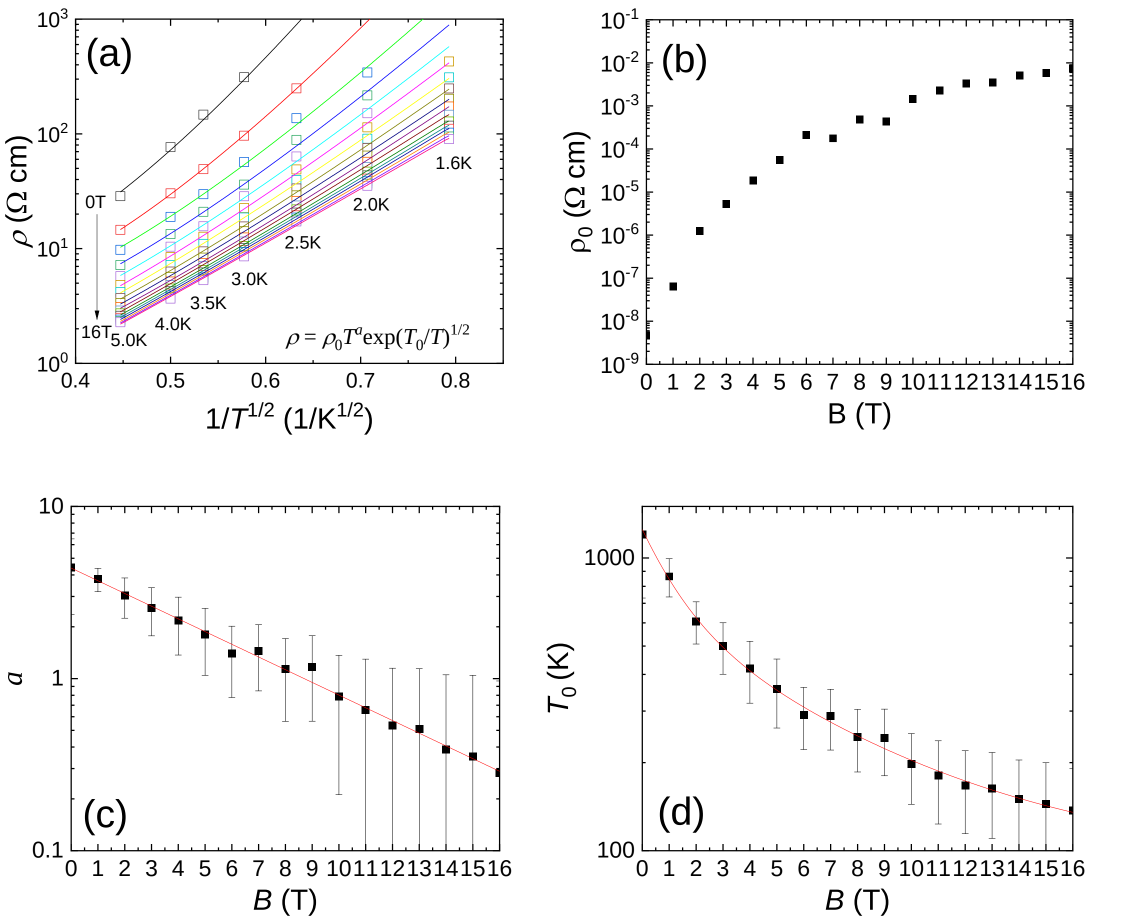

Fig. S4 Resistivity measured at various temperatures with magnetic field applied along out-of-plane [001] axis for $Ga_{1-x}Mn_xAs_{0.79}P_{0.21}$ sample with Mn x of 4%. (a) Scaling of resistivity versus $T^{-1/2}$ at different magnetic fields for lower temperatures. The curves are fits of Eq. (3); (c) and (d) show field dependence of fitting parameters *a* and T_0. The red curve in (c) is a fit of an exponential decay. The red curve in (d) is a fit of a double exponential decay function.

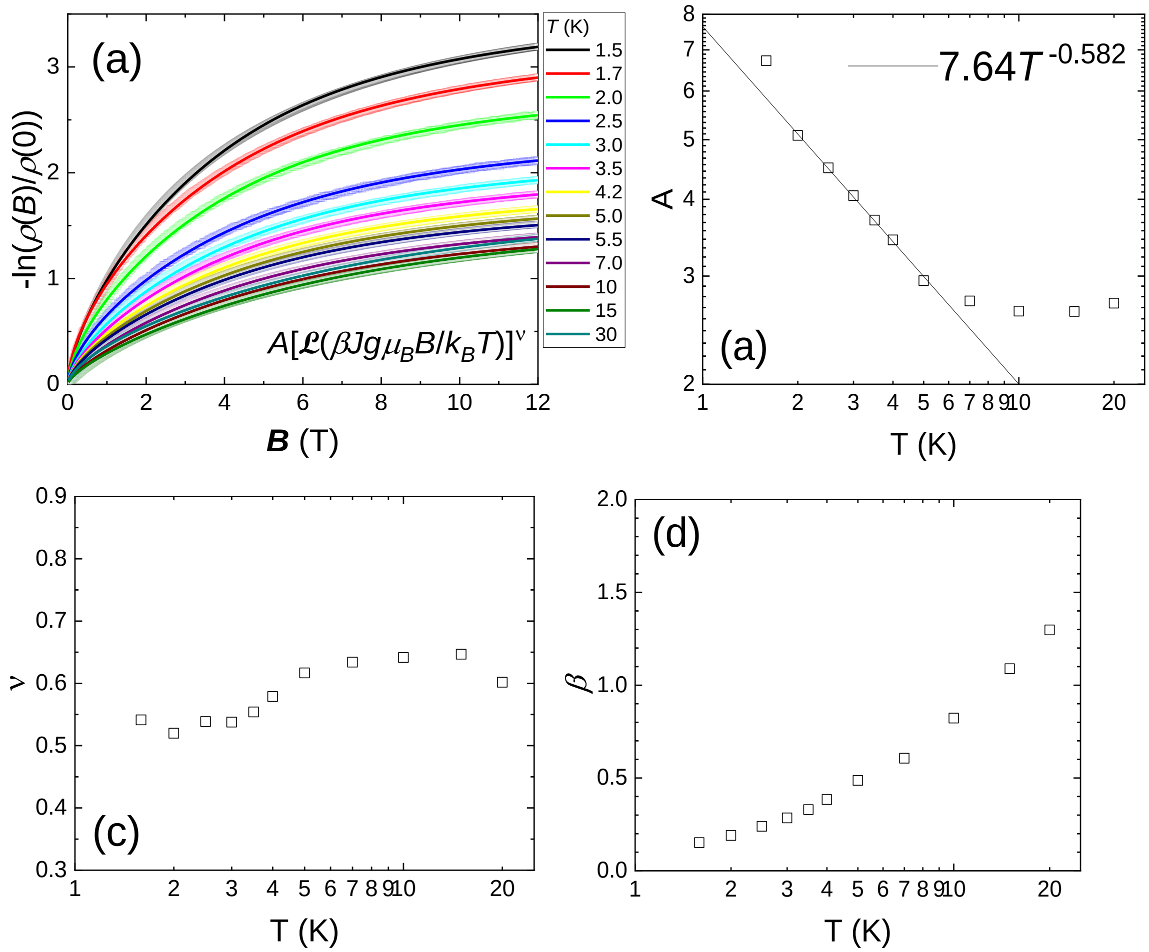

Fig. S5 (a) shows field dependence of $-\ln(\rho(B)/\rho(0))$ for $Ga_{0.94}Mn_{0.06}As_{0.79}P_{0.21}$ film at various temperatures below Curie temperature. The fits show as solid curves using Langevin equation $A(T)L(\beta Jg\mu_B B/k_B T)^{\nu}$, where $L(x)$ is a modified Langevin function $L(x) = \coth(x) - 1/x$, $x = \beta Jg\mu_B B/k_B T$; J = 5/2 is the angular moments of Mn ion, g = 2.0 is the g-factor, μ_B is the Bohr magneton, k_B is the Boltzmann constant and β is a rescale factor of spin system. (b, c, d) The fitting parameters A, ν, and β as function of temperature.

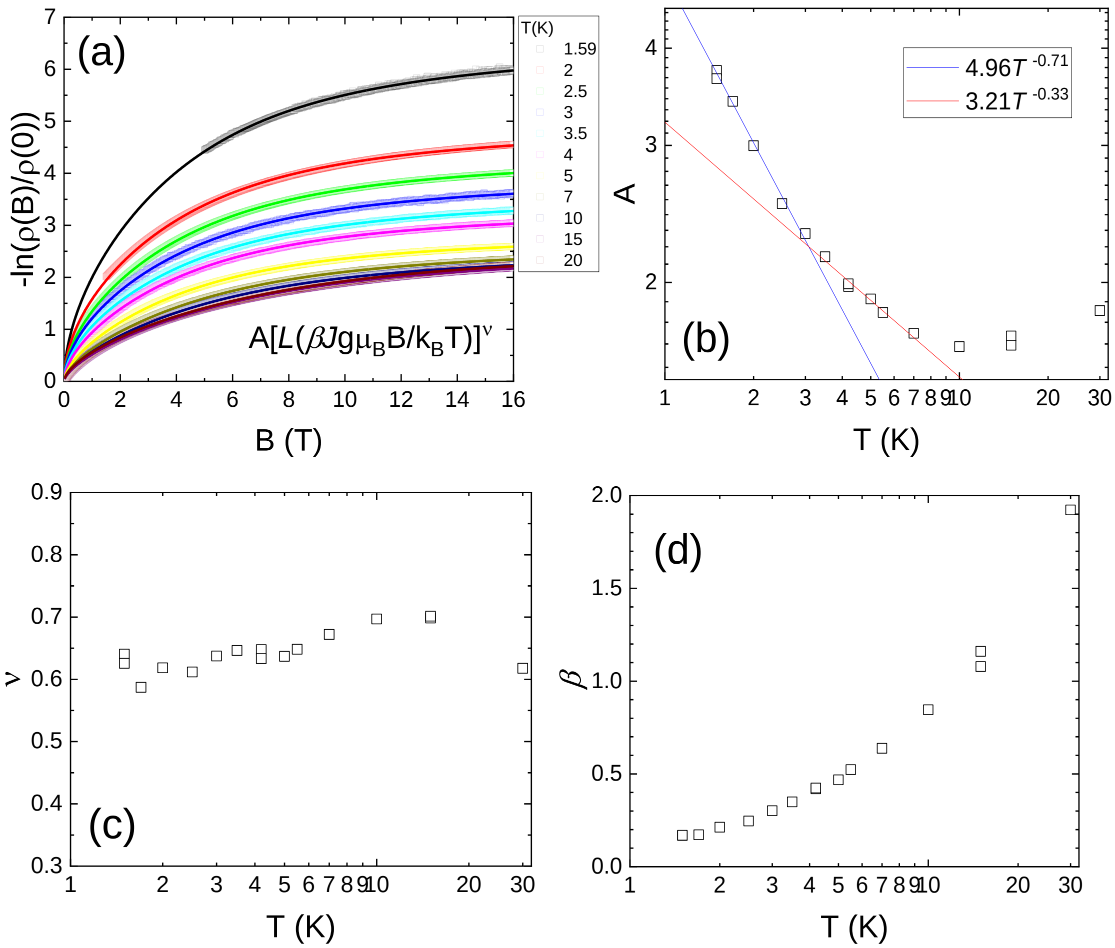

Fig. S6 (a) shows the field dependence of $-\ln(\rho(B)/\rho(0))$ for $Ga_{0.96}Mn_{0.04}As_{0.79}P_{0.21}$ film at various temperatures below Curie temperature. The fits show as solid curves. using Langevin equation $A(T)L(\beta\, Jg\mu_B B/k_B T)^{\nu}$. (b, c, d) The Fitting parameters A, ν, and β as a function of temperature.