Dilute magnetic semiconductor (DMS)

- Goal: search for semiconductors with room-temperature ferromagnetism
- Reason: spin-polarized carrier sources and possible new spintronic devices
- typically a non-magnetic semiconductor doped with a small amount of open shell transition metal
- carrier-mediated ferromagnetism, in which the ferromagnetism is caused by the interaction of the magnetic ions with the carriers
- Curie temperature and other magnetic properties can be modified by changing the carrier concentration with electric fields (gates) or with optical excitation

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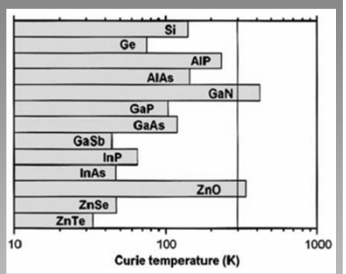
- Zener mean-field model of ferromagnetism by Dietl
- Tc for various p-type semiconductors containing 5% of Mn and 3.5×10^{20} holes/cc
- Some materials ZnO, TiO2, SnO2, In2O3
- For example:
  Co doped anatase TiO2 on LaAlO3
  ➔ room-temperature ferromagnetism with a magnetic moment of 0.32μB/Co
  ➔ Tc was estimated to be higher than 400 K.



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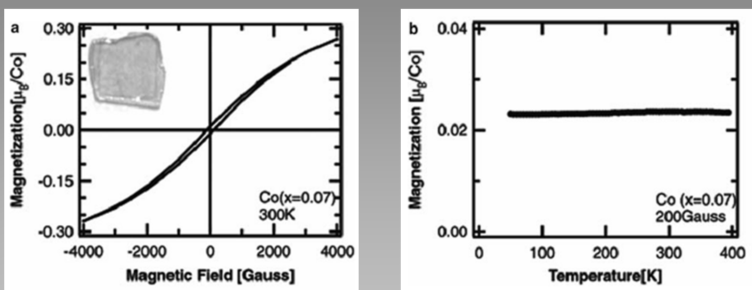
magnetic secondary phases

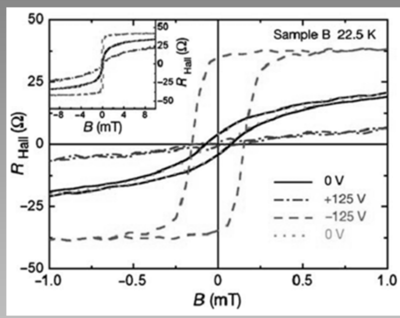
- Such as magnetic clusters of a metallic phase embed-ded in the oxide matrix
- showed magnetic hysteresis also
- ferromagnetism caused by the secondary pha se is not carrier mediated and therefore the electrical control of the spin polarization cannot be realized.
- Anomalous Hall Effect (AHE) (X)
- Traditional magnetic measurements (X)
- magnetic circular dichroism (MCD)
- ➔ direct information on the spin polarization in a semicon-ductor band so that one can associate the ferromagnetism to the band structure

Co0.07Ti0.93O2



electric-field control of ferromagnetism with a field-effect transistor structure

- (In,Mn0.03)As
- hall bar devices with voltage gates to control the carrier concentration in (In,Mn)As
- ferromagnetism could be enhanced and removed depending on the hole population in the (In,Mn)As
- Tc below 200K for (In, Mn)As



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- The magnetization of a 60 nm thick Co doped TiO2 changed as much as 15% at room temperature with +/- 30V applied an adjacent ferroelectric PbZr0.2Ti0.8O3 layer to pole it.
- Strain effect from PZT

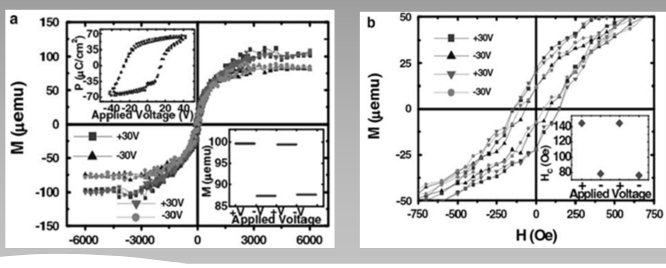

Fig. 3.20 The same hysteresis loops for anatase $Co_{0.07}Ti_{0.93}O_2$ after several electric voltage poling on the PZT layer shown in (**a**) from −6,000 to 6,000 Oe (**b**) from −750 to 750 Oe. The two *insets* in (**a**) are the electric polarization vs. applied field of the $PbZr_{0.2}Ti_{0.8}O_3$ layer and the saturation magnetization of $Co_{0.07}Ti_{0.93}O_2$ as a function of the applied voltage on $PbZr_{0.2}Ti_{0.8}O_3$. The *inset* in (**b**) plots the coercive field (H_c) of $Co_{0.07}Ti_{0.93}O_2$ as a function of the applied voltage on $PbZr_{0.2}Ti_{0.8}O_3$ (Reproduced from [80])

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