KU LEUVEN

NUCLEAR AND RADIATION PHYSICS

Sub-lattice displacement in multiferroic Rashba semiconductor (Ge,Mn)Te (IS648)

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on behalf of EC-SLI collaboration

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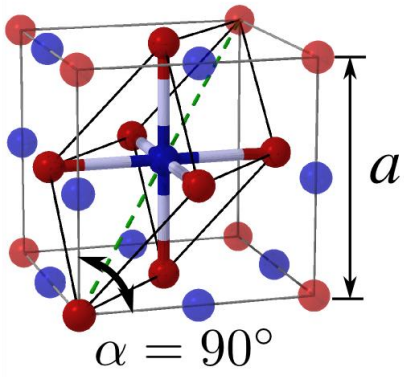
multiferroic Rashba semiconductors

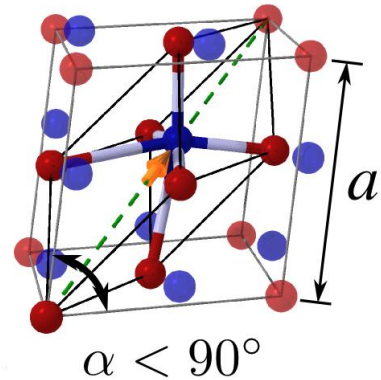
(MUFERS)

cubic Fm3m → rhombohedral R3m



GeTe

(Tc = 700 K)



Ferroelectricity → Rashba effect

(Ge,Mn)Te

Ferromagnetism → Zeeman effect

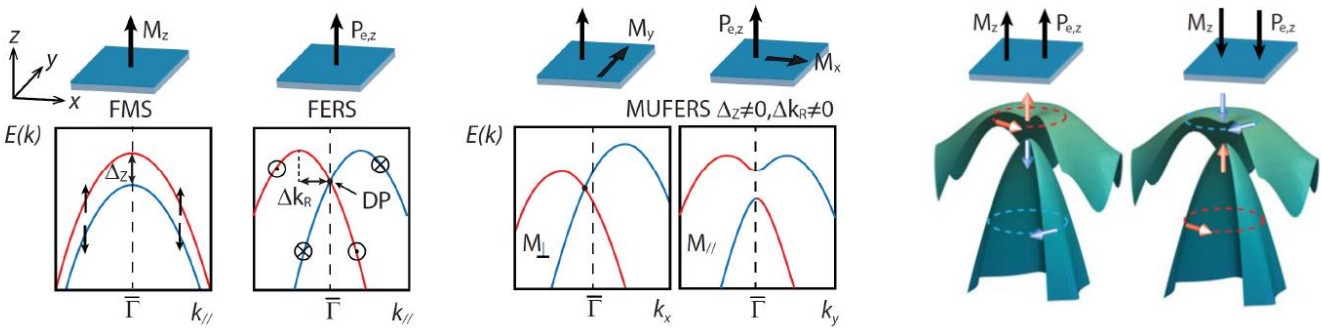
multiferroic Rashba semiconductors

(MUFERS)

magnetization (M) - Mn sub-lattice

ferroelectric polarization (P) - both Ge and Mn sub-lattices

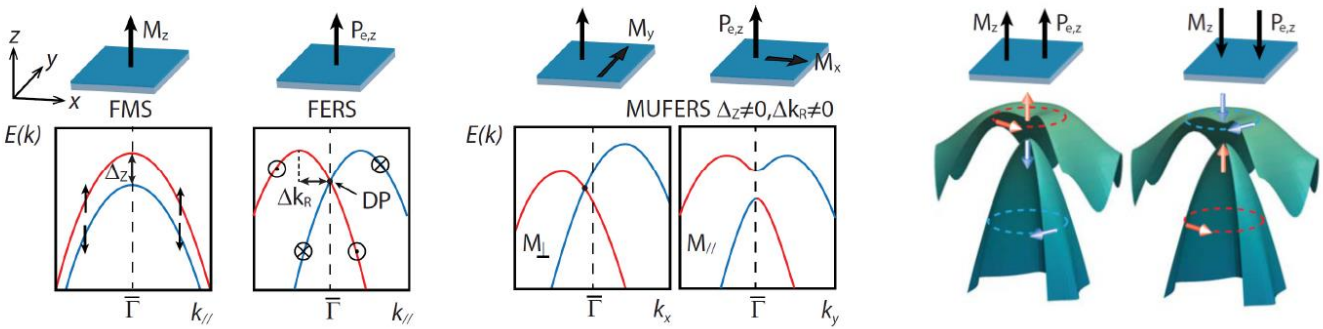
magnetoelectric coupling → control spin structure → { electric fields / magnetic fields



Physical Review X, 8(2), p.021067 (2018)
Nature Communications 7, 13071 (2016), Adv. Mater. 28, 560–565 (2016)

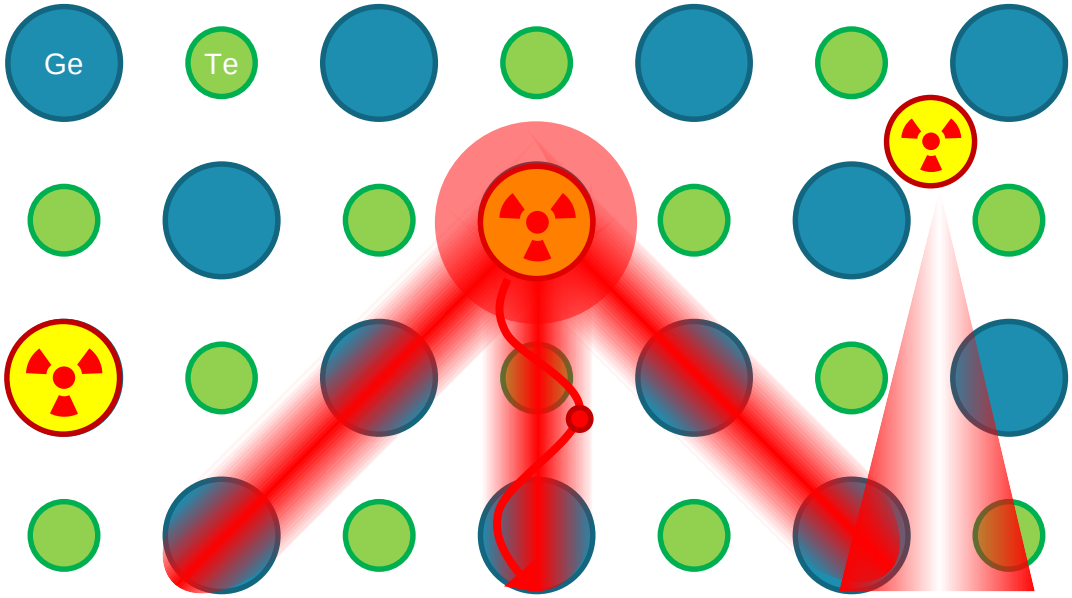
MUFERS and emission channeling

- determine the **magnitude** and **direction** of the Mn sub-lattice displacement as a function of:
  - Mn concentration
  - temperature
  - applied magnetic field

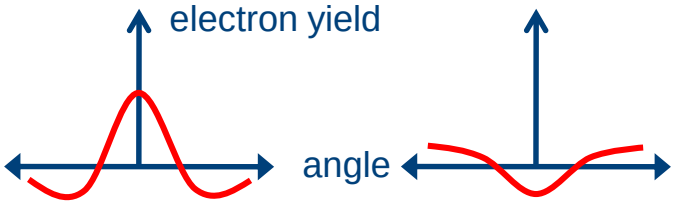


Physical Review X, 8(2), p.021067 (2018)
Nature Communications 7, 13071 (2016), Adv. Mater. 28, 560–565 (2016)

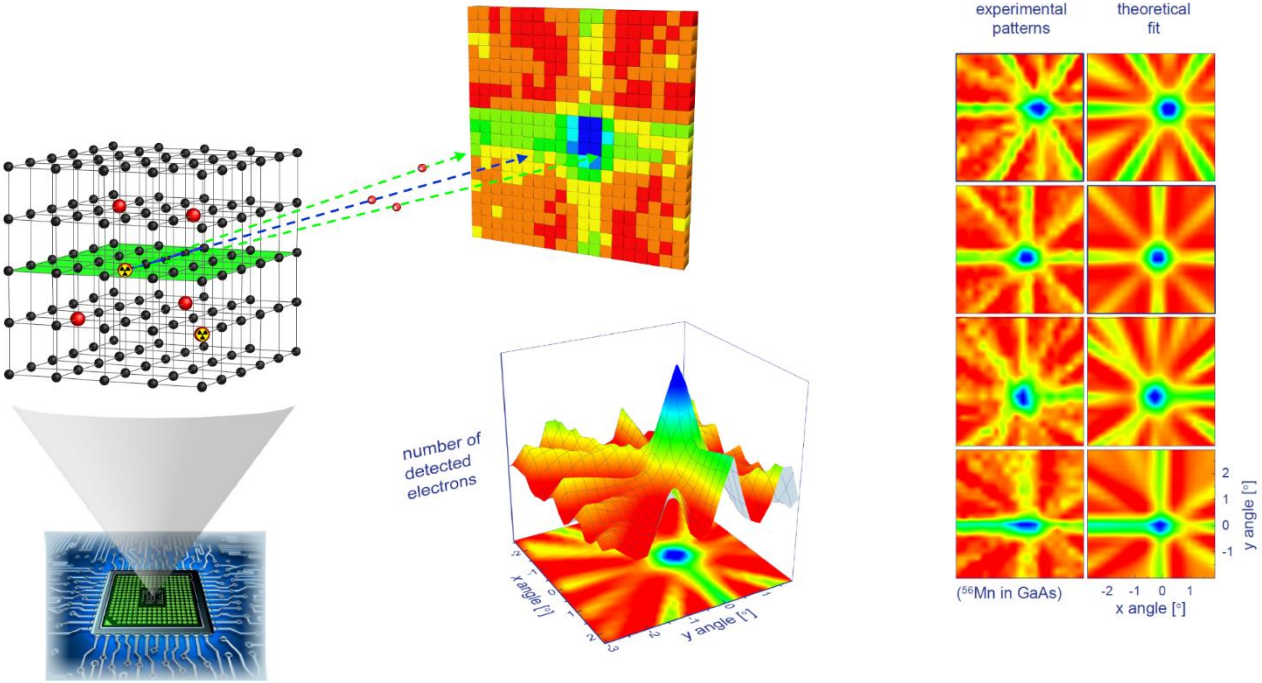
electron emission channeling



^{56}Mn (2.6 h) β^- decay

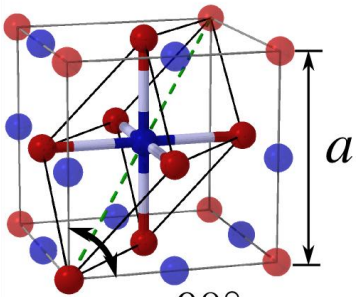


electron emission channeling



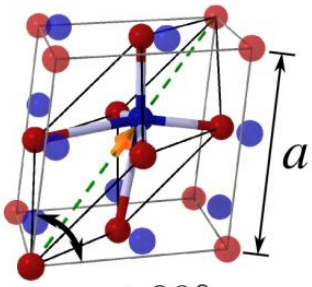
Ge displacement in GeTe

cubic

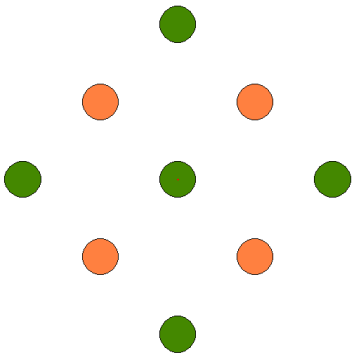


$\alpha = 90°$

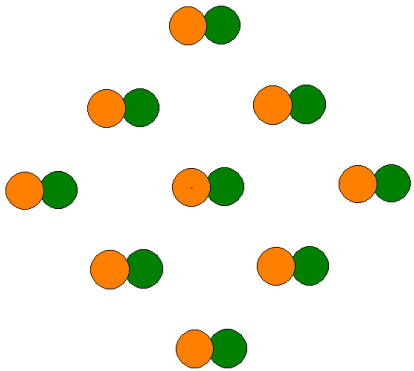
rhombohedral



$\alpha < 90°$

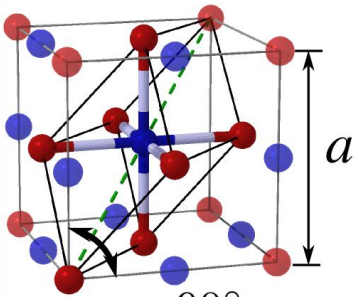


Sub-lattice displacement projected along <100>



Ge displacement in GeTe

cubic



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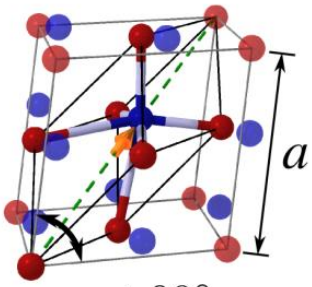
rhombohedral



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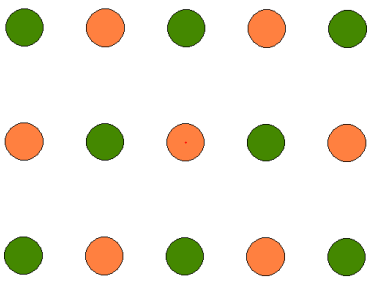
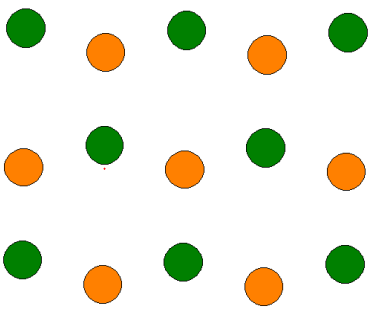
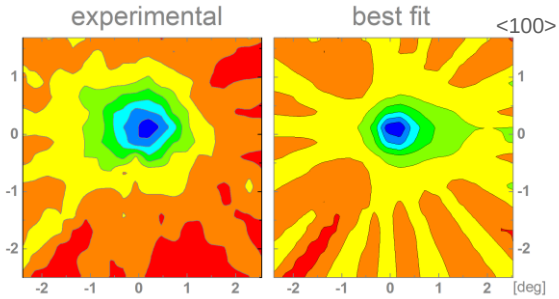


Sub-lattice displacement projected along <110>



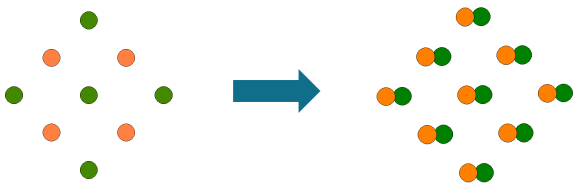
Mn displacement **magnitude** in GeTe

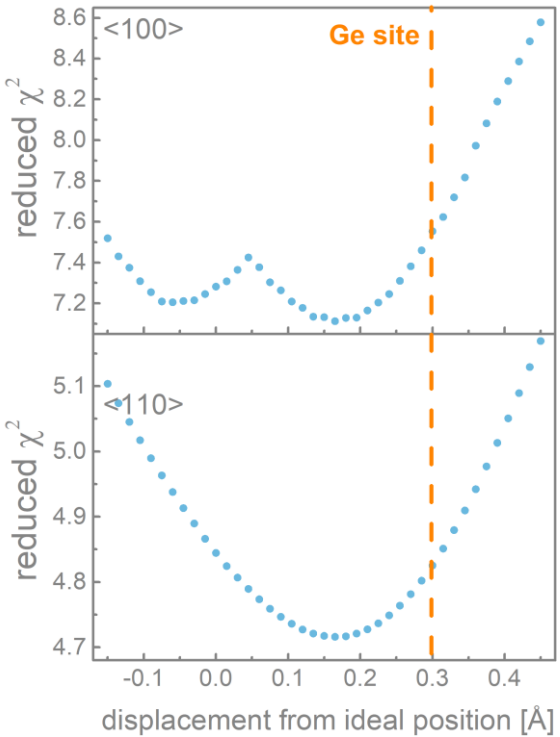


along <100> @ T = 100 K

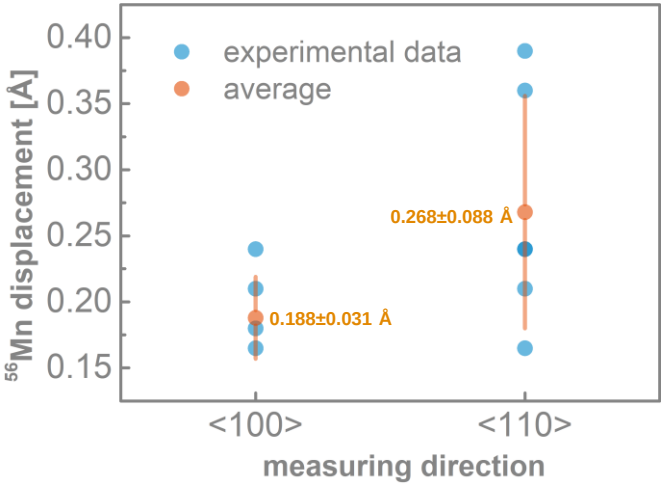
T = 100 K & T = 298 K

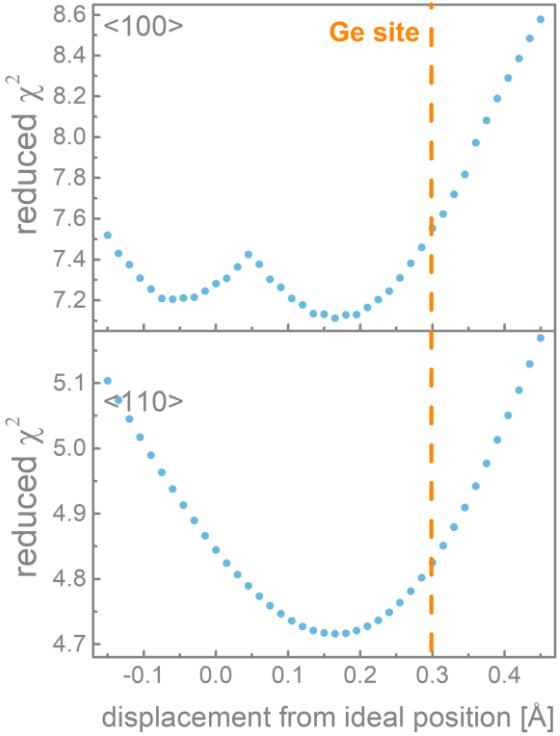
→ FE phase





Mn displacement **magnitude** in GeTe





<100> vs <110>:

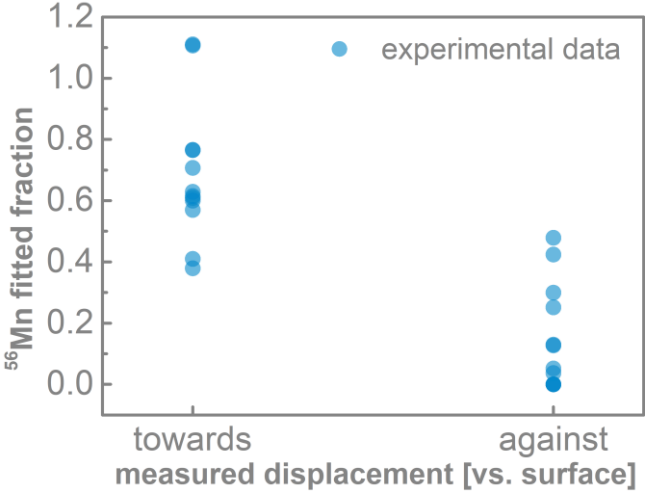
- ❑ higher precision

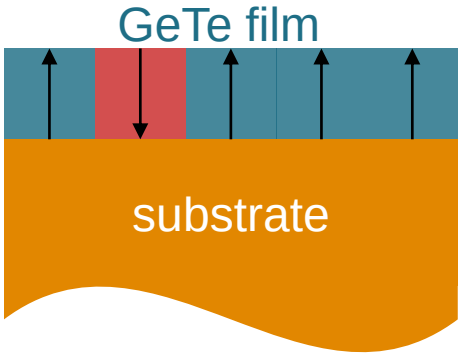
(uncertainty of 0.03 Å)

direction:

- ❑ Mn displacement // Ge displacement

direction of Mn displacement in GeTe





- spontaneous FE polarization
  (interaction with substrate?)

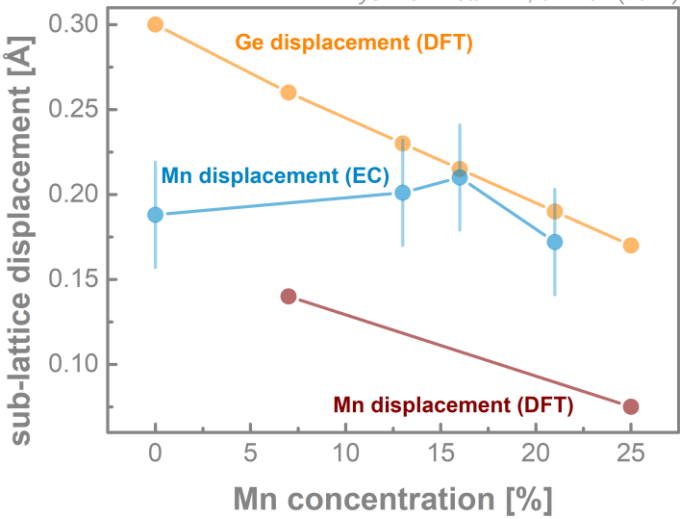
Mn displacement in (Ge,Mn)Te

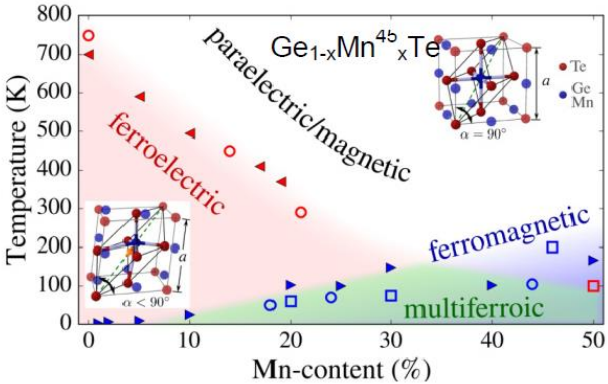
(as a function of Mn concentration)

13% Mn 17% Mn 21% Mn

@100 K → FE phase

Phys. Rev. Lett. 112, 047202 (2014)





^{56}Mn displacement:

- ❑ **larger** than calculated by DFT
- ❑ **constant** over [%] range

summary

- EC can probe the **magnitude** and **direction** of Mn sub-lattice displacement
  - high precision – 0.03 Å
  - Mn displacement close to Ge
- indications of **spontaneous FE polarization** in GeTe
  - large fractions of displacement towards the surface
- unexpected Mn displacement in (Ge,Mn)Te:
  - **constant** over probed Mn concentration range
  - **higher** than calculated by DFT

outlook:

- low-temperature EC-SLI with magnetic field

acknowledgements

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EL-SLI

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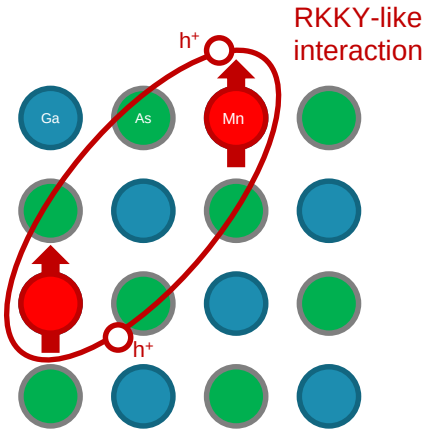
FCT

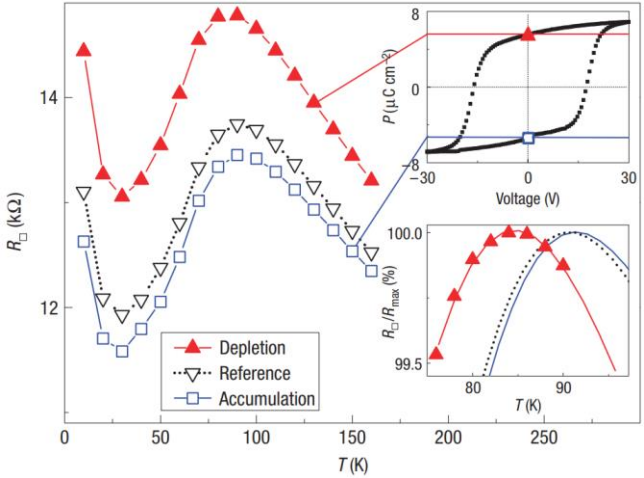
Co-funded by the Horizon 2020 programme of the European Union

ferromagnetism in semiconductors



high hole concentration

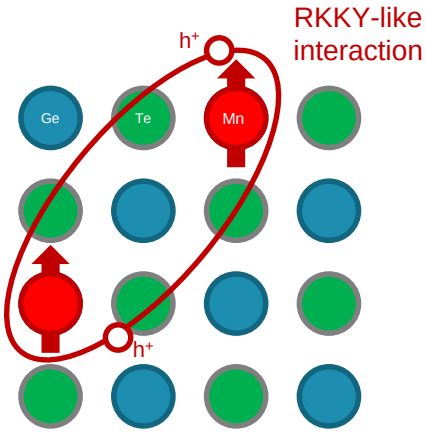
Modulate magnetic response through electric field of a poled FE material



Nature materials 7.6 (2008): 464

→ non-volatile control of non-trivial spin texture

ferromagnetism

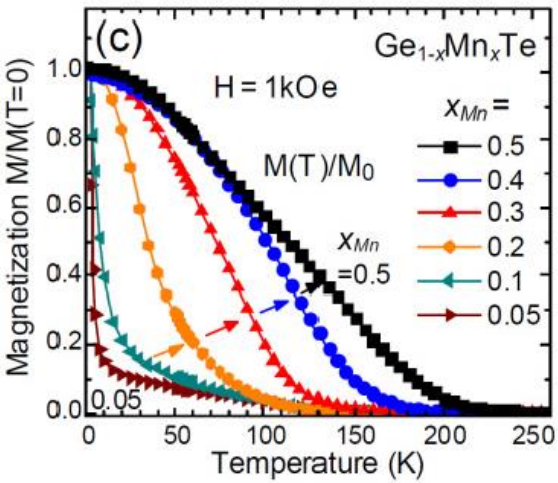


GeTe and (Ge,Mn)Te

high hole concentration

high Mn solubility (up to 50% Mn)

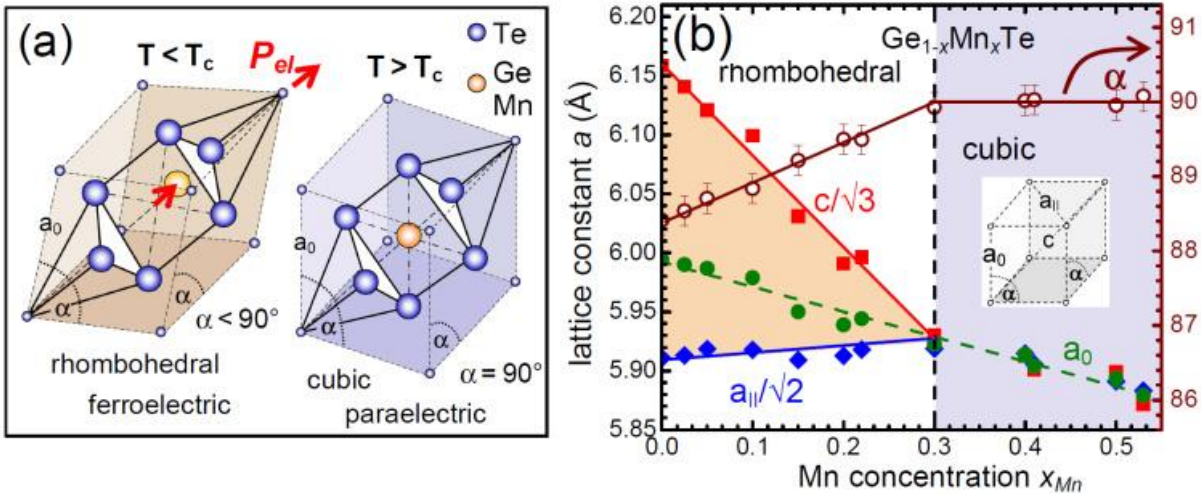
Phys. Rev. Lett. 112, 047202 (2014)



Curie temperatures up to 200 K

ferroelectricity

Phys. Rev. Lett. 112, 047202 (2014)

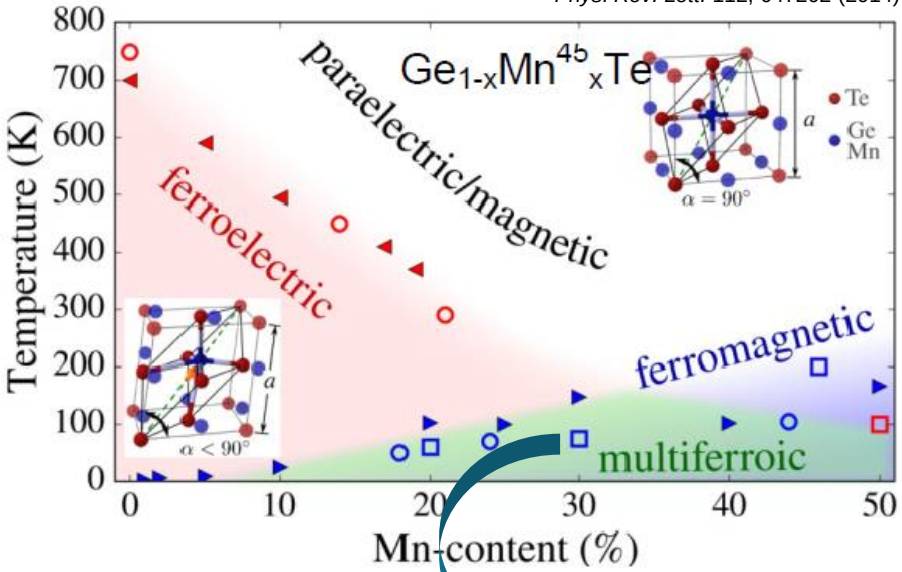


- cubic Fm3m rock salt → polar rhombohedral R3m phase
- sub-lattice displacement (up to 0.3 Å for GeTe) → ferroelectricity
- critical temperature up to 700 K for GeTe

→ decrease with increasing Mn concentration

multiferroic phase diagram

Phys. Rev. Lett. 112, 047202 (2014)



coexistence of FM and FE at ~100 K

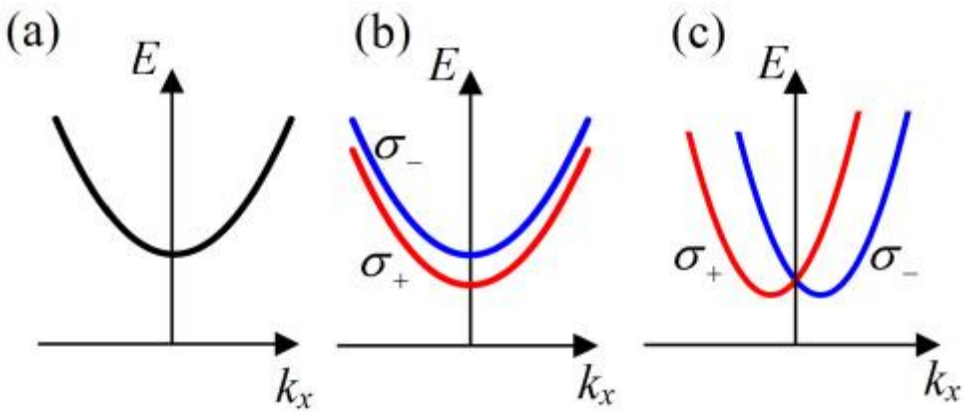
magnetoelectric coupling

multiferroic Rashba semiconductors

(MUFERS)

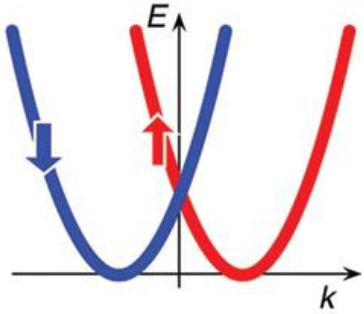
Ferromagnetism → Zeeman effect

Ferroelectricity → Rashba effect



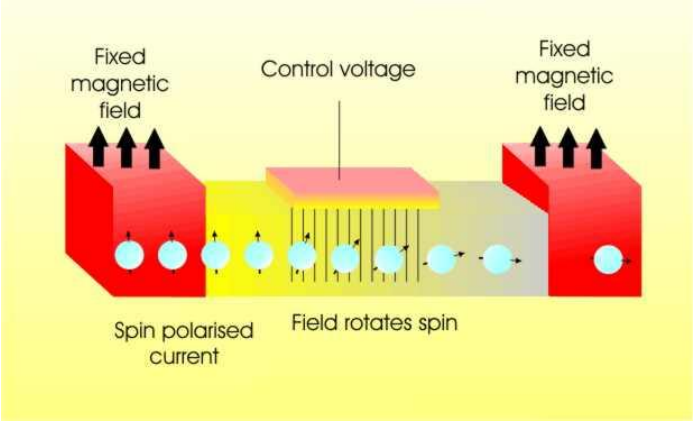
Optics express, 19(23), 23475-23482.

Rashba effect

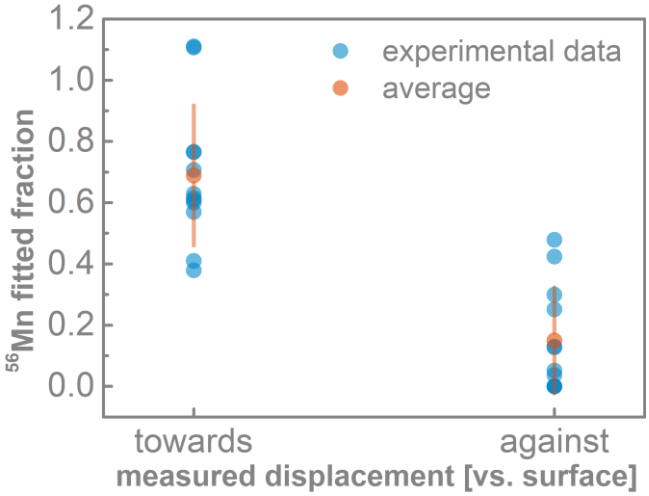


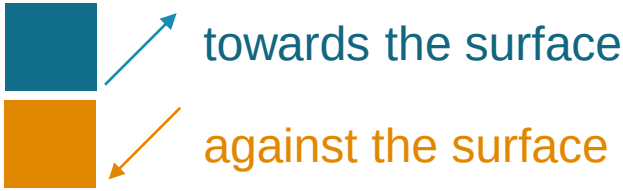
Momentum-dependent splitting of spin bands in bulk crystals

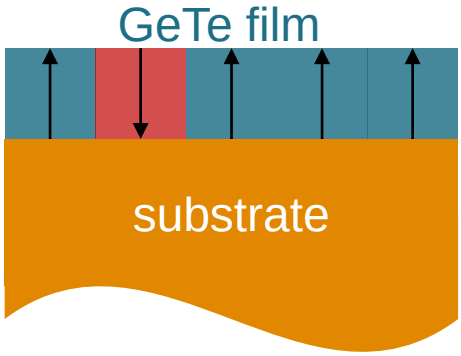
enables control of spin without magnetic fields

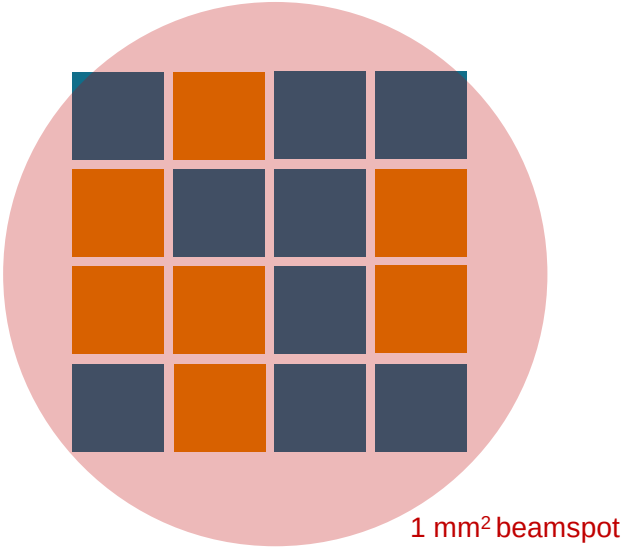


direction of Mn displacement in GeTe









direction of Mn displacement in GeTe