Ultrafast Optical Control of Ferromagnetic Order in InMnAs/GaSb Heterostructures

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Outline

- Background :
  III-V Magnetic Semiconductors
  Light Induced Ferromagnetism
- Experimental methods:
  Two-color time resolved MOKE
- Experimental results:
  First demonstration of **ultrafast optical softening** in InMnAs
- Discussion and summary

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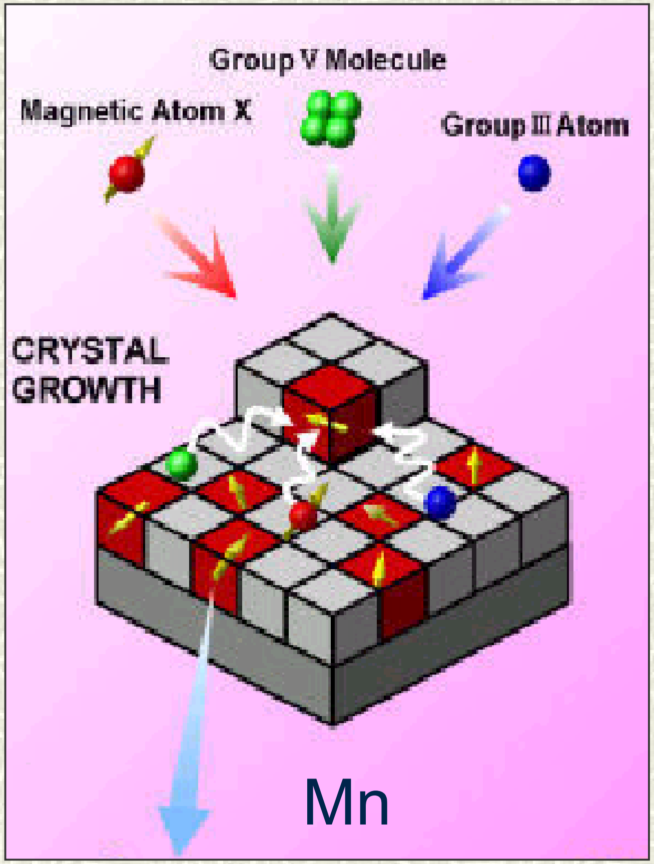
(III,Mn)V Semiconductors

Hole mediated ferromagnetism (Mn^{2+} with $3d^5$, S=5/2)

Low-temperature MBE grown structures

- InMnAs: $T_c < 60$ K
- InGaMnAs: $T_c < 120$ K
- GaMnAs: $T_c < 172$ K
- GaMnN : $T_c >$ RT (?)
- GaMnSb: $T_c >$ RT (?)



Objectives

- Understand **optical properties** of $III_xMn_{1-x}V$.
- Understand how **ferromagnetism influences** optical properties.

⬇

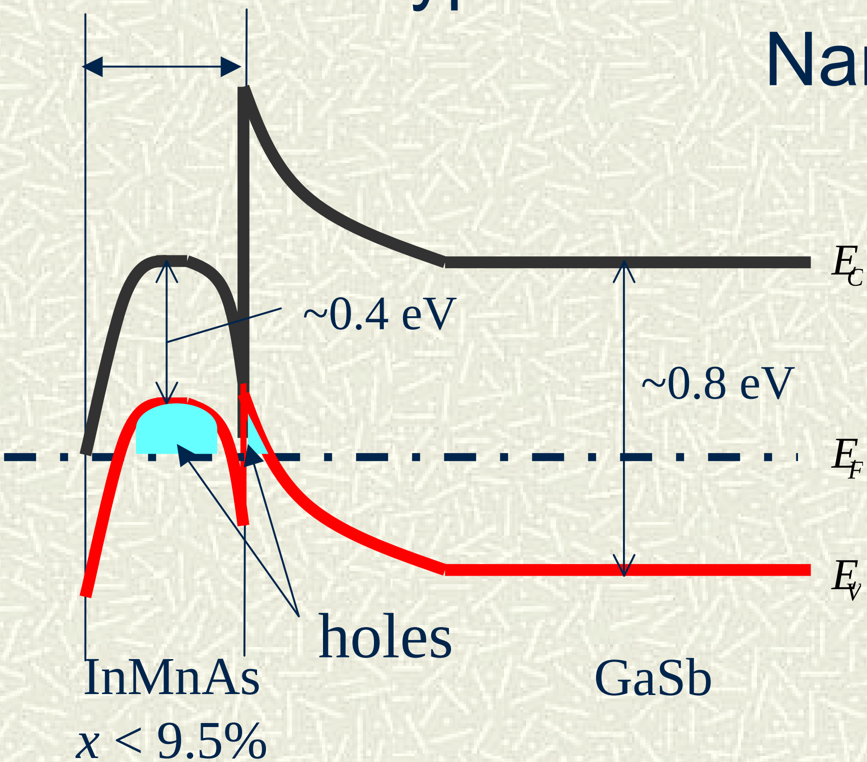
- **Optical manipulation** of ferromagnetic order.
- Develop novel concepts for **opto-spintronic devices.**

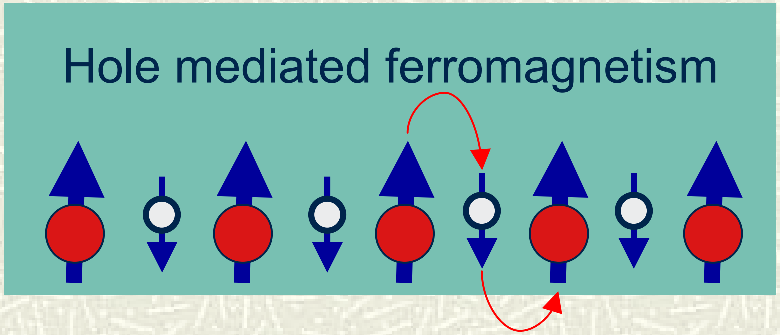
InMnAs/GaSb Heterostructures

T_c = 30-60 K

Type-II broken gap heterostructures

Narrow gap

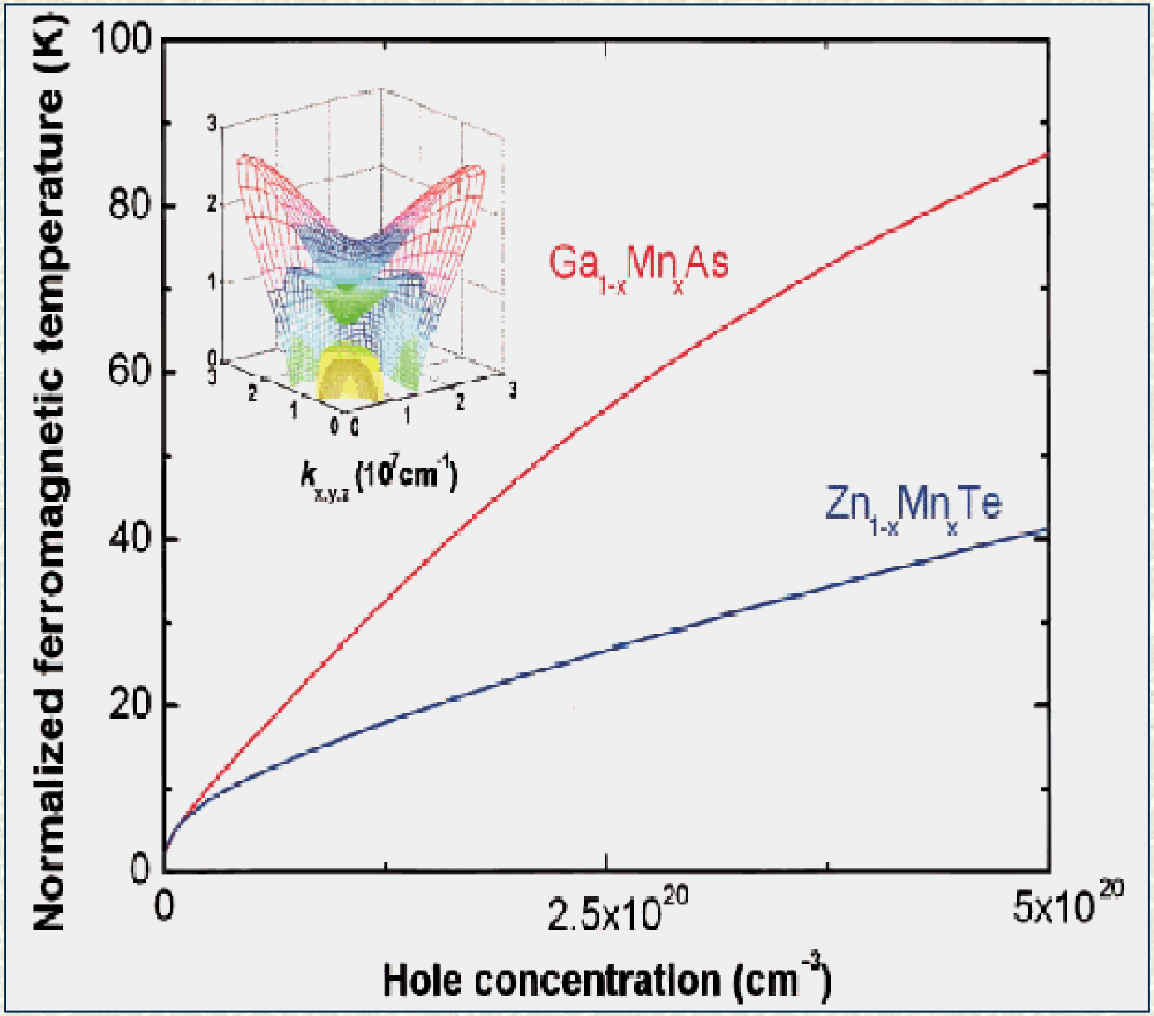




Hole density ~ 1 x 10^{19} cm^{-3}

Hole mobility ~ 300 cm^2/Vs

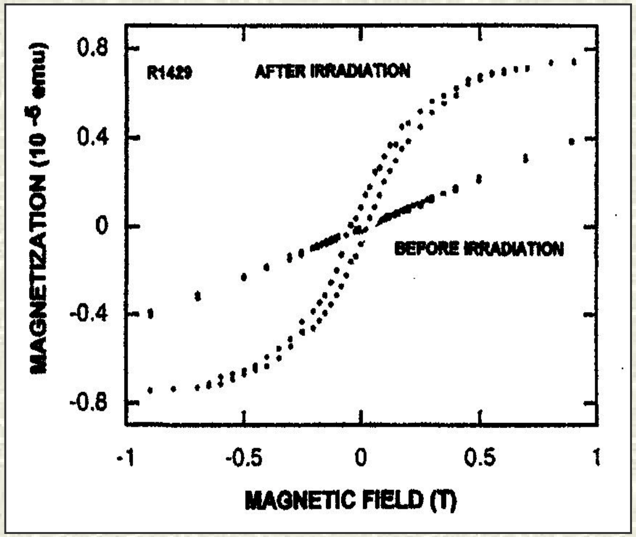
Hole Mediated Ferromagnetism



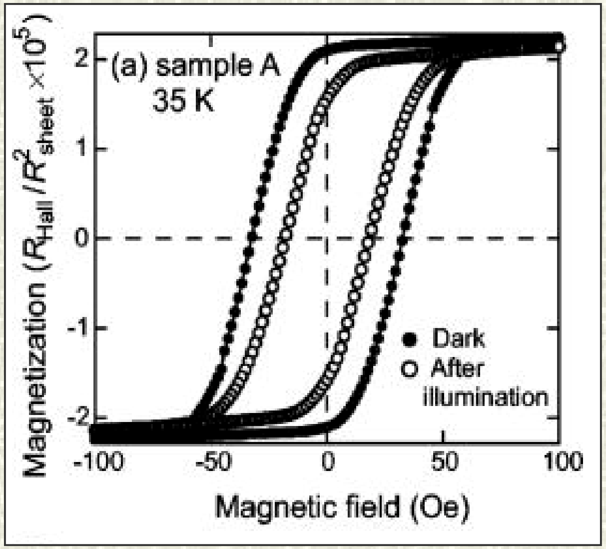
T. Dietl, H.Ohno and F.Matsukura, Science **287**,1019 (2000)

Light-Induced Ferromagnetism

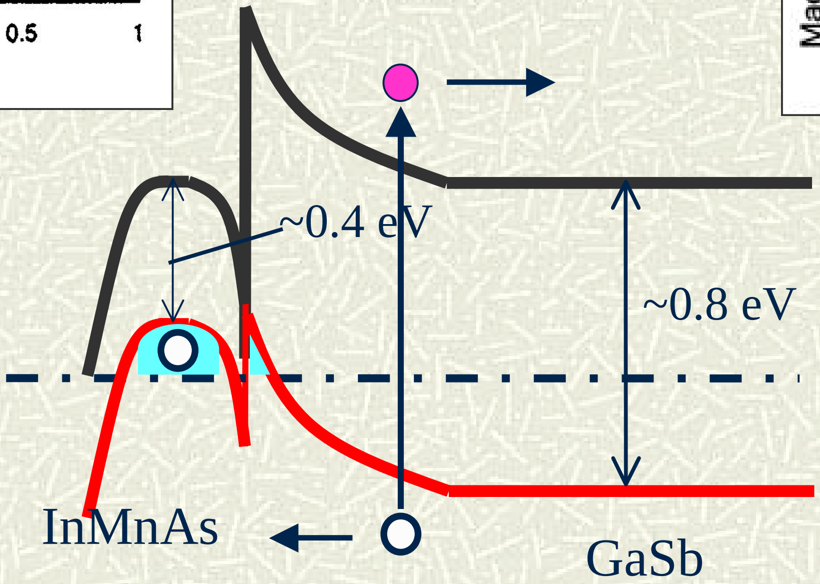
S. Koshihara *et al.*, PRL 78, 4617 (1997)



A. Oiwa *et al.*, APL 78, 518 (2001)



- Persistent photoeffect
- Hole density increases



Ultrafast Study of Ferromagnets

Ni and Co:

E. Beaurepaire *et al.*, Phys. Rev. Lett. 76, 4250 (1996).
M. Aeschlimann *et al.*, Phys. Rev. Lett.79, 5158 (1997).
A. Scholl *et al.*, Phys. Rev. Lett. 79, 5146 1997).
J. Hohlfeld *et al.*, Phys. Rev. Lett. 78, 4861 (1997).
J. Güdde *et al.*, Phys. Rev. B 59, R6608 (1999).
B. Koopmans *et al.*, Phys. Rev. Lett. 85, 844 (2000).

$CoPt_3$:

G. Ju *et al.*, Phys. Rev. B 57, R700 (1998).
E. Beaurepaire *et al.*, Phys. Rev. B 58, 12134 (1998).
L. Guidoni *et al.,* Phys. Rev. Lett. 89, 017401 (2002).

Sr_2FeMoO_6

T. Kise *et al.,* Phys. Rev. Lett. 85, 1986 (2000).

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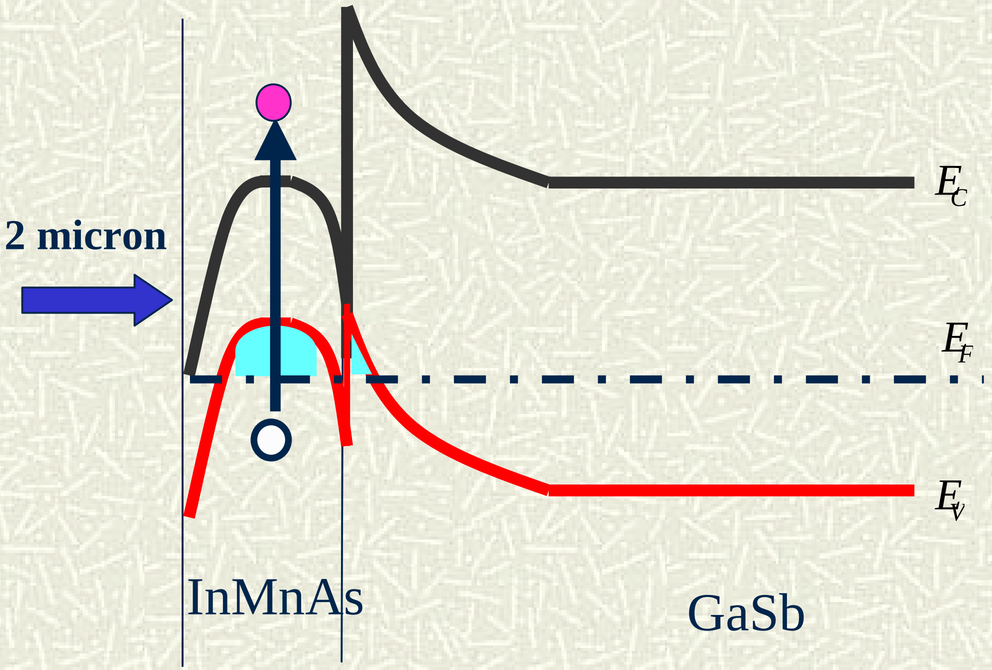
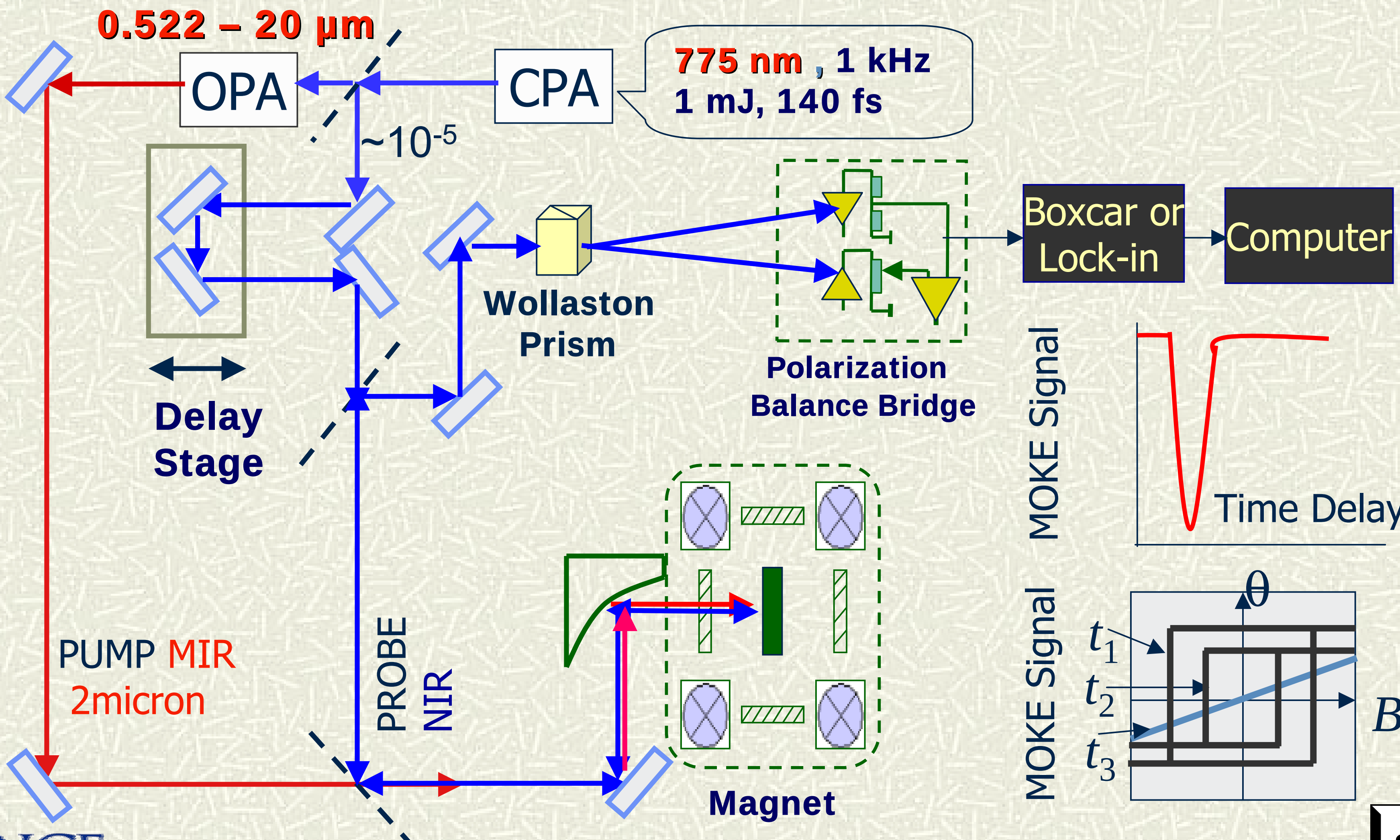
Selective Pumping

- Photo-induced **transient carriers** interact with Mn ions: control of magnetism
- Our technique: **Two-color, ultrafast** MOKE
- Our system: **Ferromagnetic semiconductors**



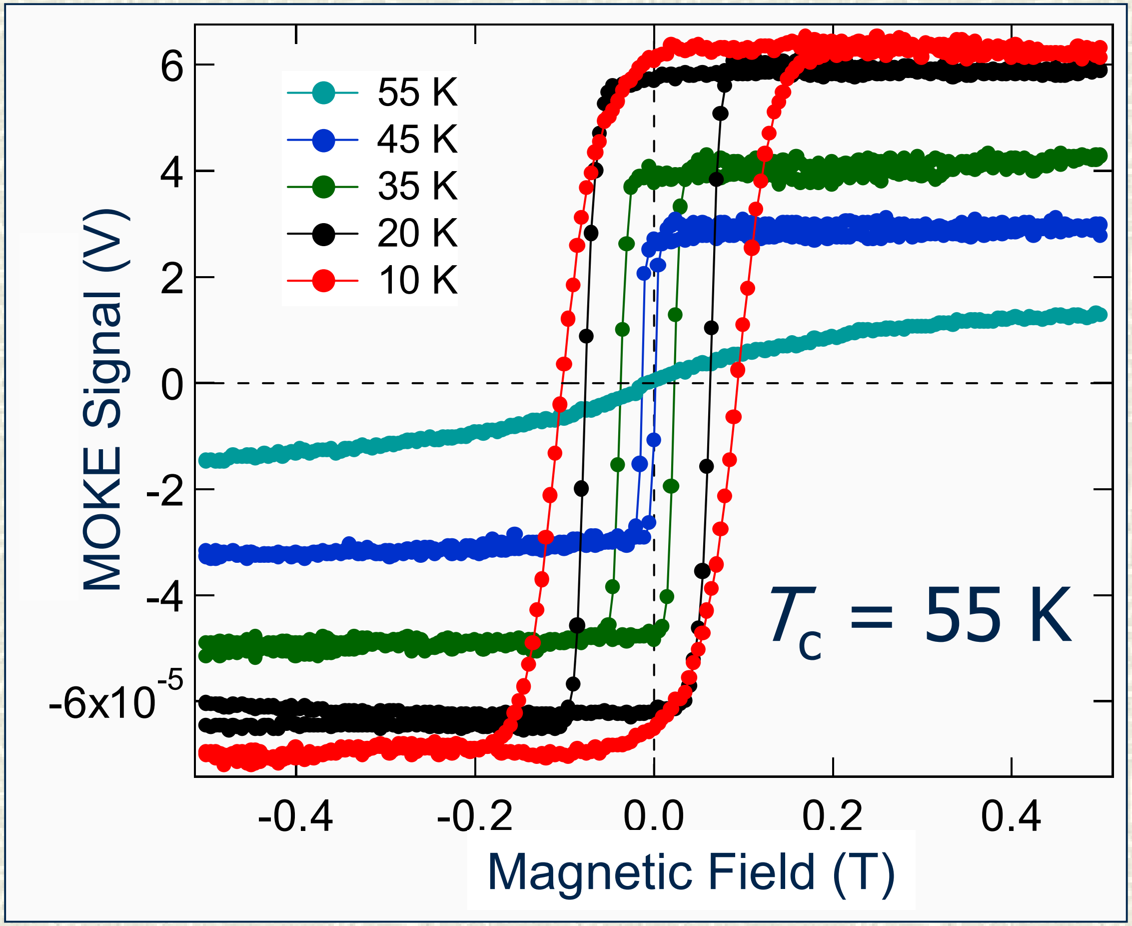
MIR pump → Avoid charge separation and persistent effect.

Two-Color Time-Resolved MOKE Setup

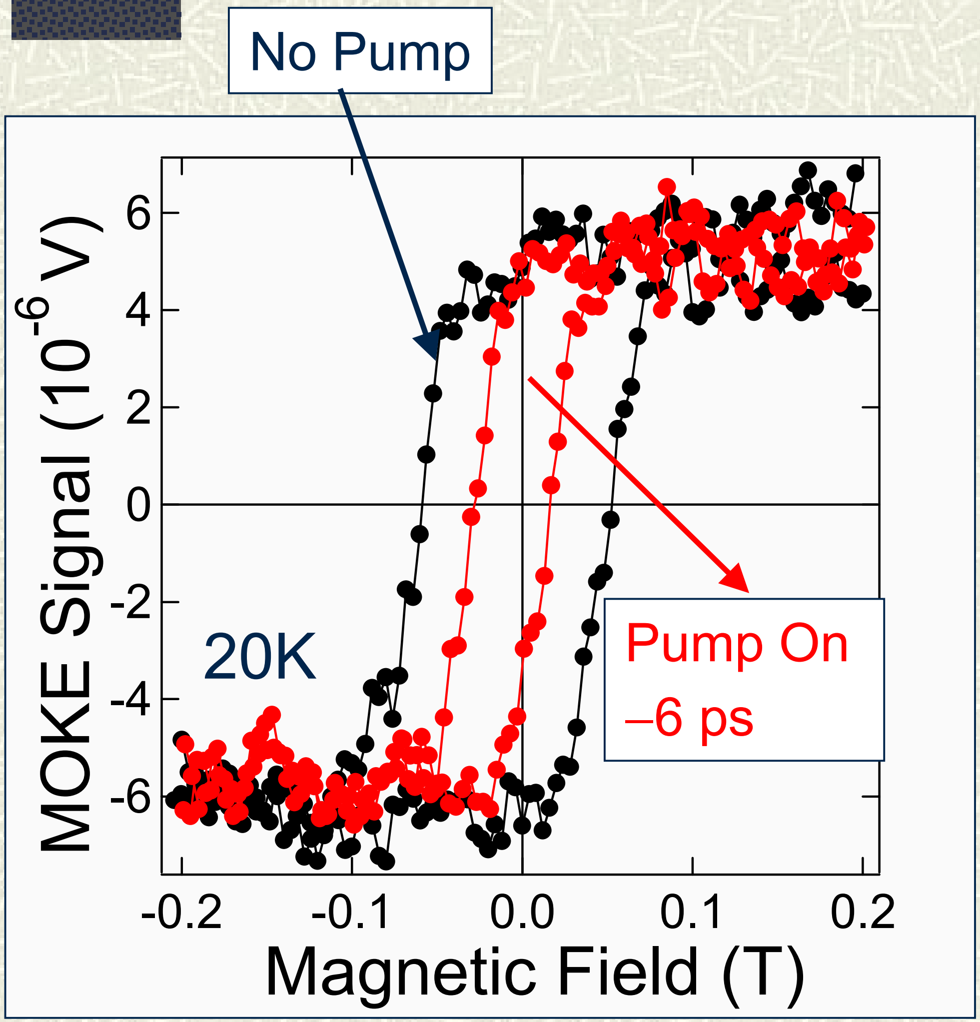


CW MOKE

$In_{0.910}Mn_{0.090}As$(25nm)/GaSb(820nm) on GaAs(100)

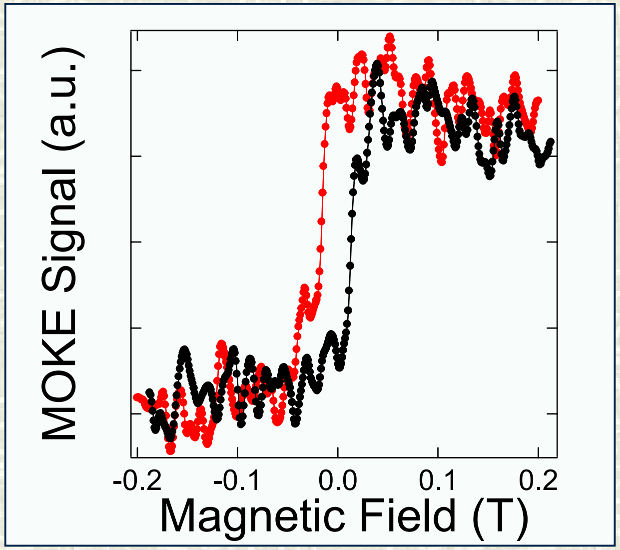


MOKE with fs Pulses

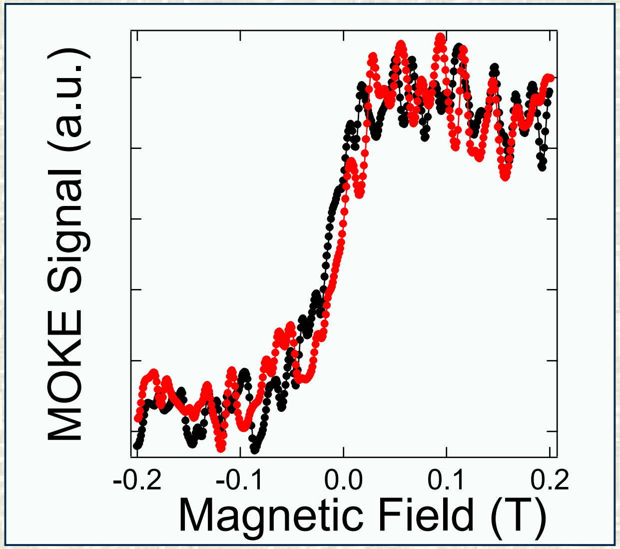


- Coercivity changes even in negative time delay
- Net magnetization doesn't change
- Possible persistent effect via two photon absorption in GaSb

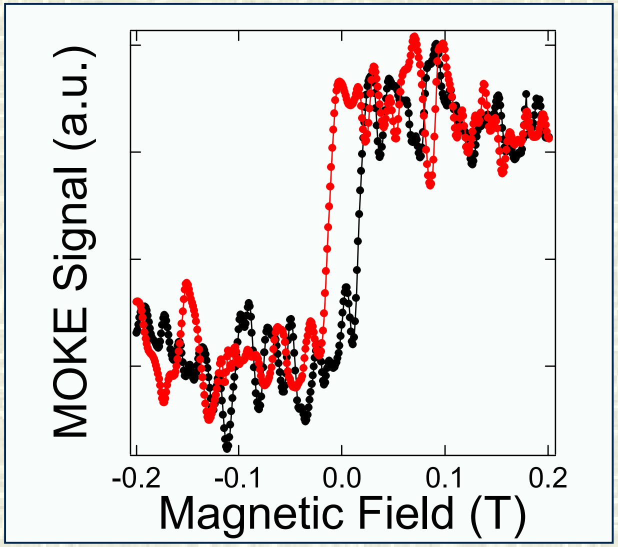
Ultrafast Photoinduced Softening



t ~ -4 ps



t ~ 0 ps



t ~ 11 ps

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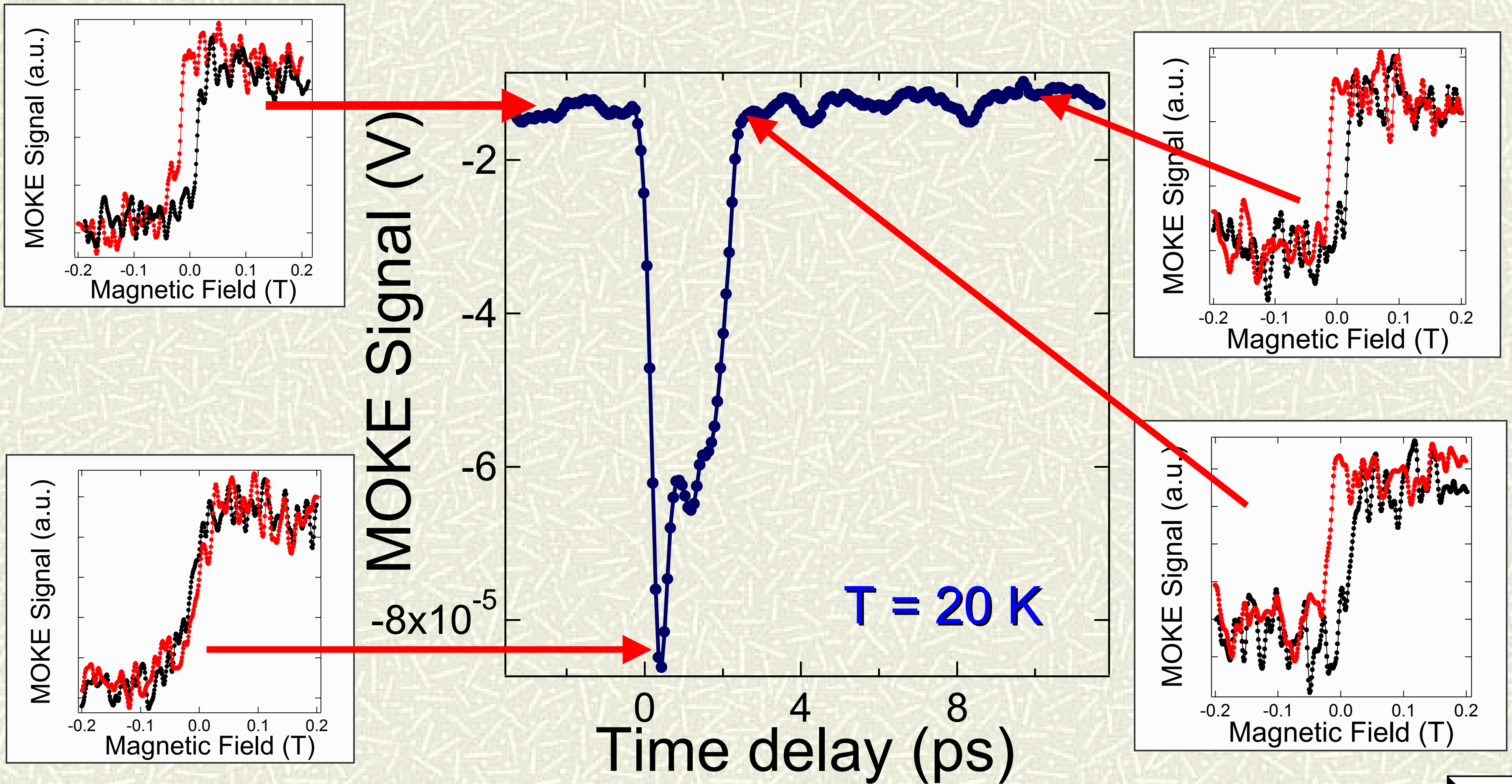
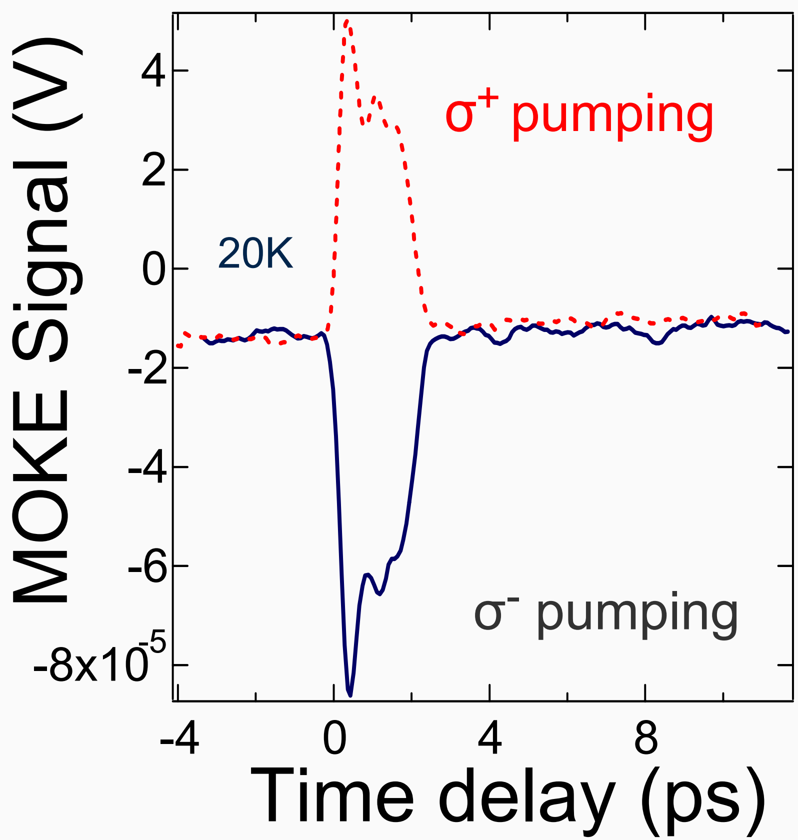
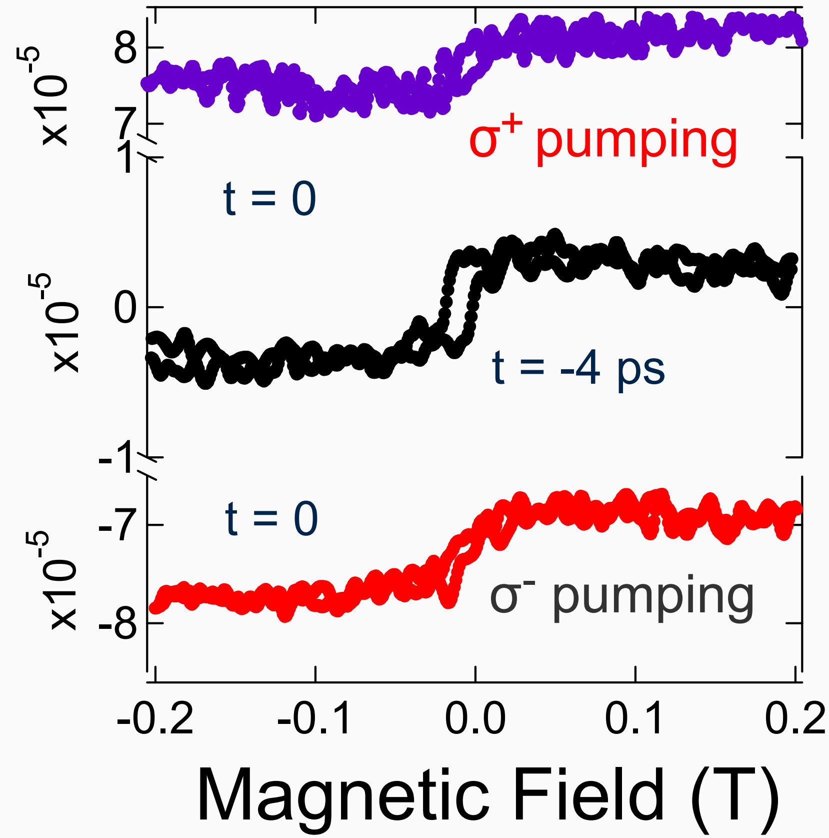
Ultrafast Photoinduced Softening

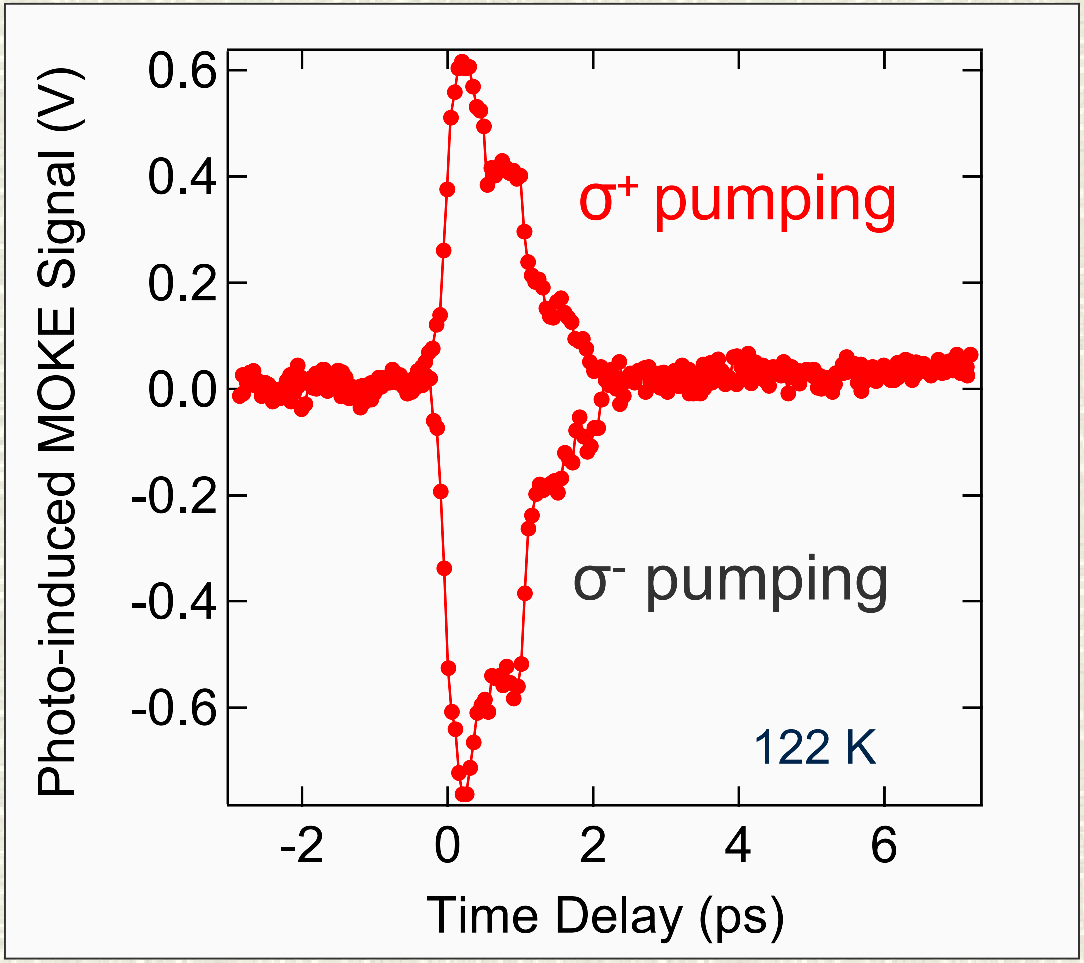


Pump Polarization Dependence





MOKE Dynamics at $T > T_c$



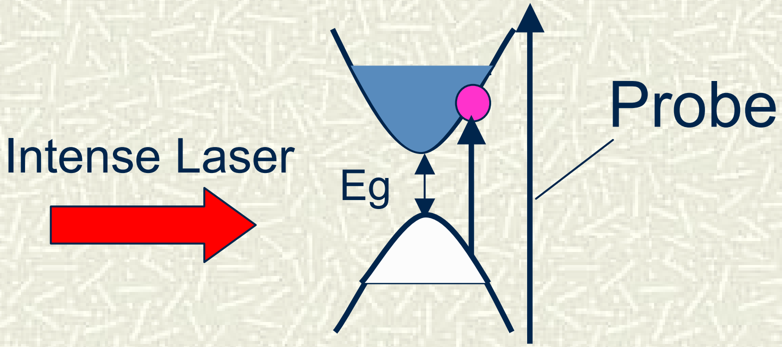
Ultrafast Shifts of Ferromagnetic Loop

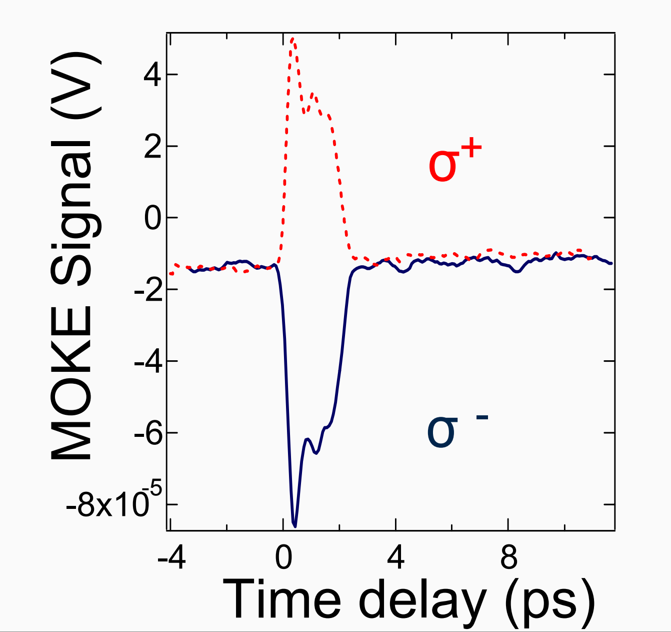
Nonlinear optical effects:
- State filling → No
- Band filling → No
- Band gap renormalization → No
- …
- Probe energy too high

Carrier spins?

Are we measuring spin lifetime?

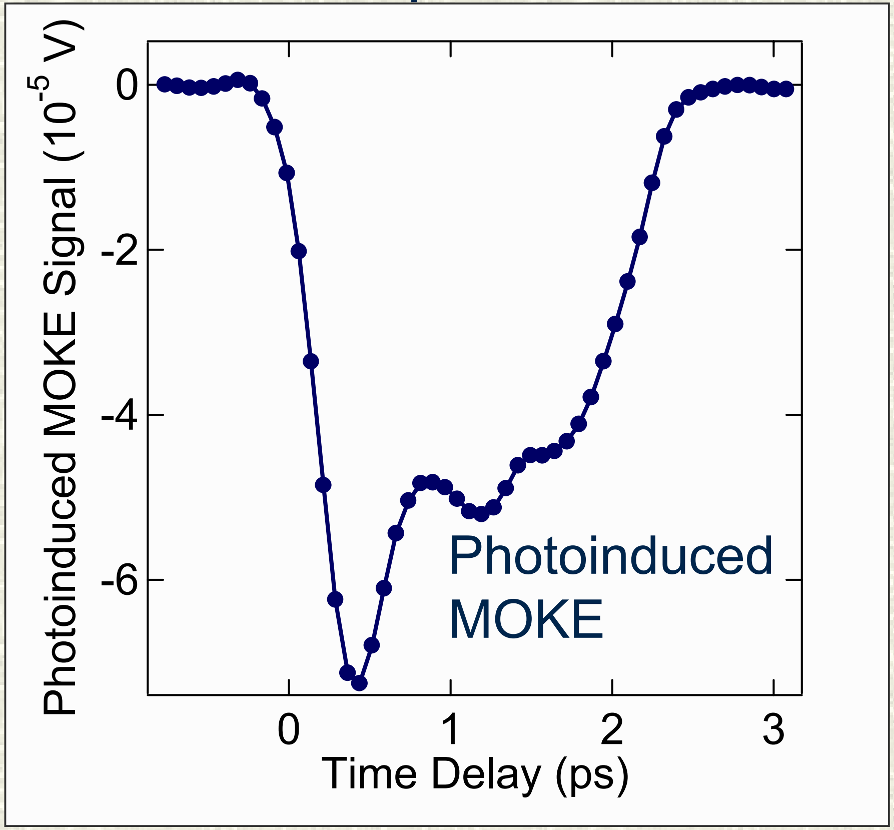
What is the carrier lifetime?



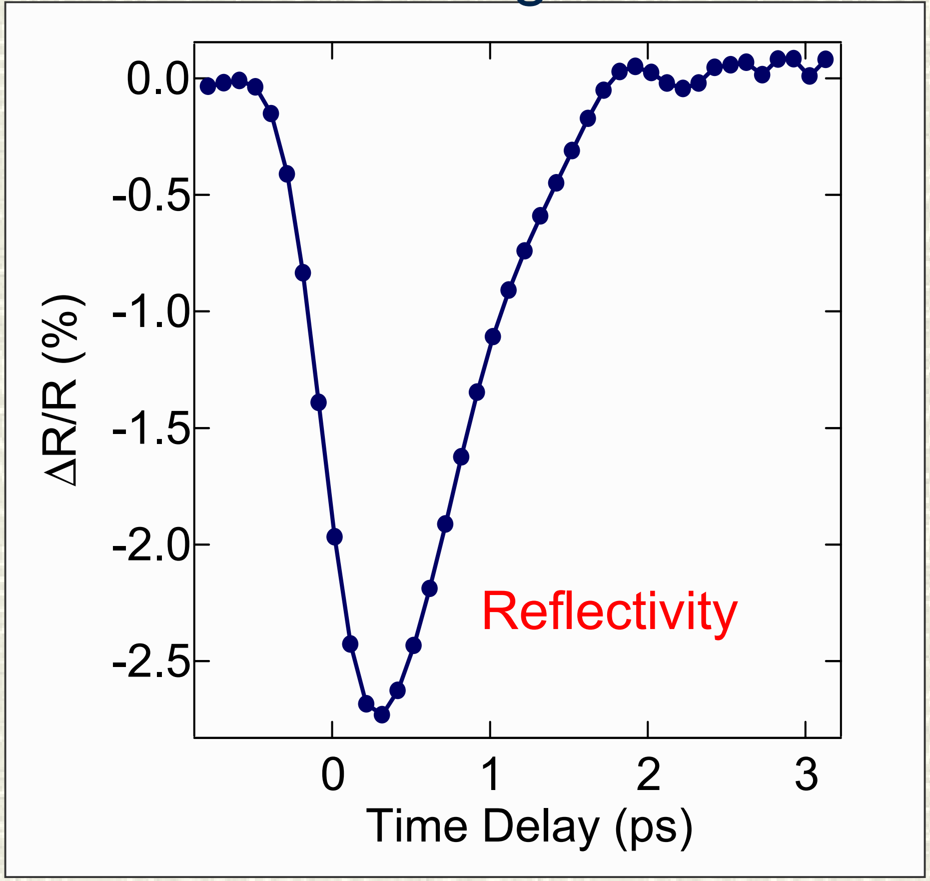


Spin & Charge Dynamics

Spin



Charge



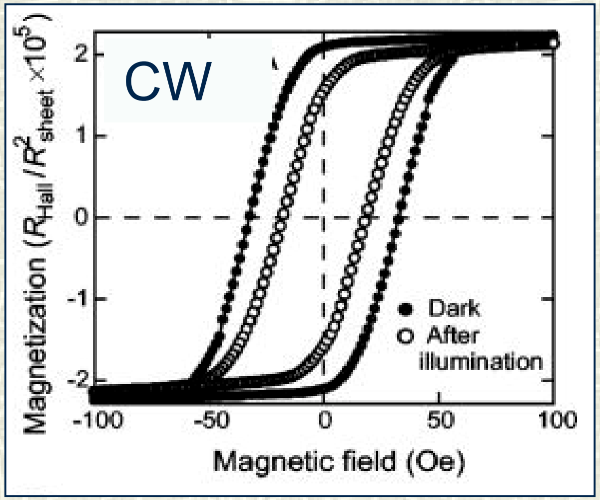
Low temp growth → ultrashort lifetimes

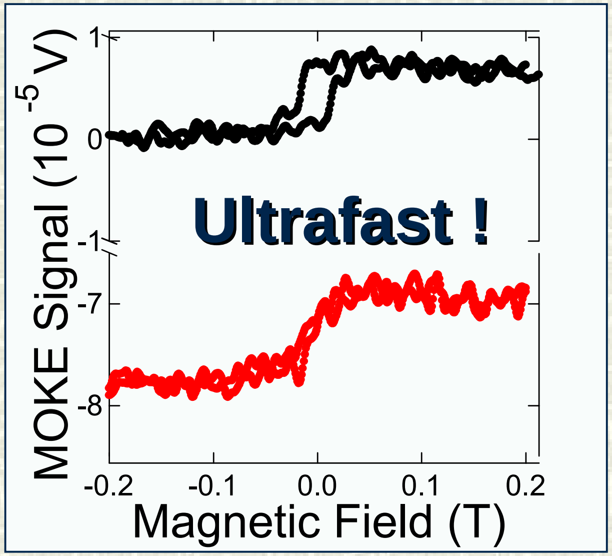
Origin of Ultrafast Softening

What determines coercivity?
-- Anisotropy & Exchange

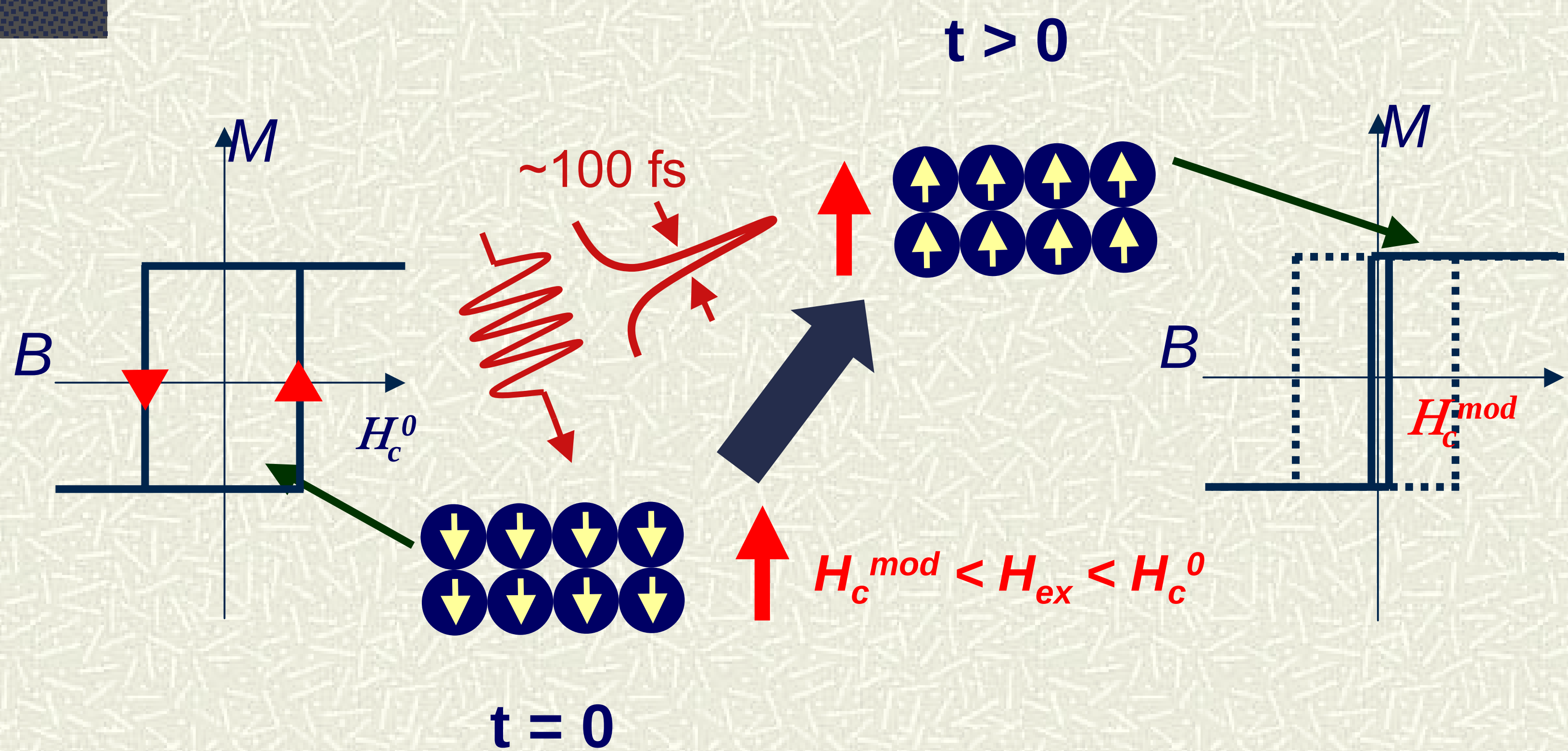
- Anisotropy does NOT change with carrier density
- Exchange increases

Decreased domain wall energy
→ Smaller coercivity





Ultrafast Recording (?)



- Spin flipping → ultrafast information recording

Summary

- First ultrafast optical study of III-V ferromagnetic semiconductors

- Optically created coherent spins in III-V ferromagnetic semiconductor

- Strong modification of ferromagnetism
  → ultrafast photoinduced softening