Magneto-optical studies of paramagnetic, wurtzite (Ga,Fe)N

J. Suffczyński[1], J.-G. Rousset[1], M. Koba[1,6], J. Papierska[1],
W. Pacuski[1], A. Golnik[1], M. Nawrocki[1], W. Stefanowicz[2],
S.Stefanowicz[2], M. Sawicki[2], R. Jakieła[2], T. Dietl[2,3,4],
A.Navarro-Quezada[5], B. Faina[5], T. Li[5], A. Bonanni[5]

1 Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
2 Institute of Physics, Polish Academy of Sciences, Warsaw, Poland;
3 Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland;
4 WPI-Advanced Institute for Materials Research (WPI-AIMR), Tohoku University, Sendai, Japan
5 Institut für Halbleiter- und Festkörperphysik, Johannes Kepler University, Linz, Austria
6 National Institute of Telecommunication, Warsaw, Poland

SEVENTH FRAMEWORK PROGRAMME
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Outlook

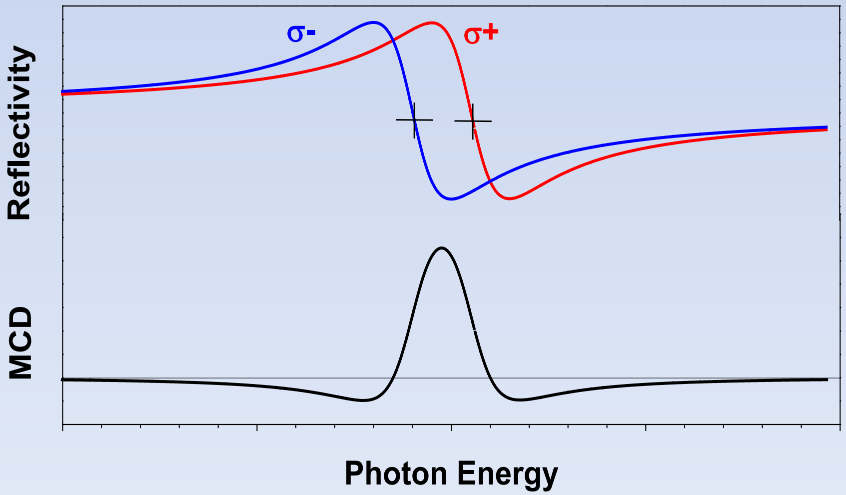
- Relation between exciton splittings, magnetic circular dichroism, and magnetization in (Ga,Fe)N
- Impact of a sample design on magnitude of Magneto-Optical Kerr Effect in (Ga,Fe)N

Magnetic Circular Dichroism (MCD)

- Arises from the difference between optical absorption or reflectivity of left and right circular polarized light
- Quantified as:

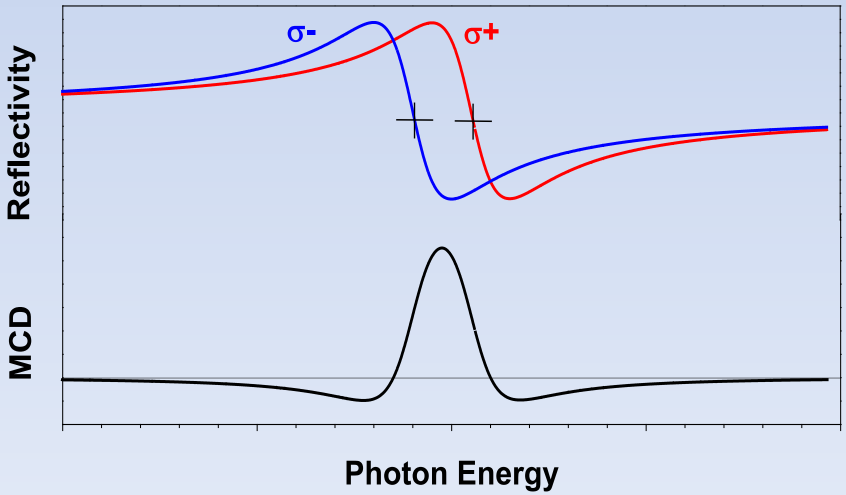
$$MCD = \frac{I_{\sigma+} - I_{\sigma-}}{I_{\sigma+} + I_{\sigma-}}$$

Motivation



- Zinc-blende DMS:
  - Single exciton transition
  - Straightforward interpretation of MCD, e.g., within a *rigid shift approximation*

Motivation



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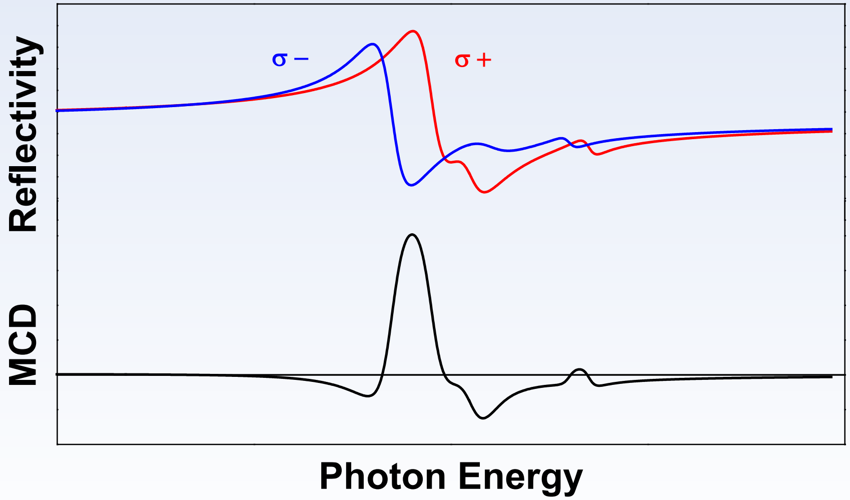
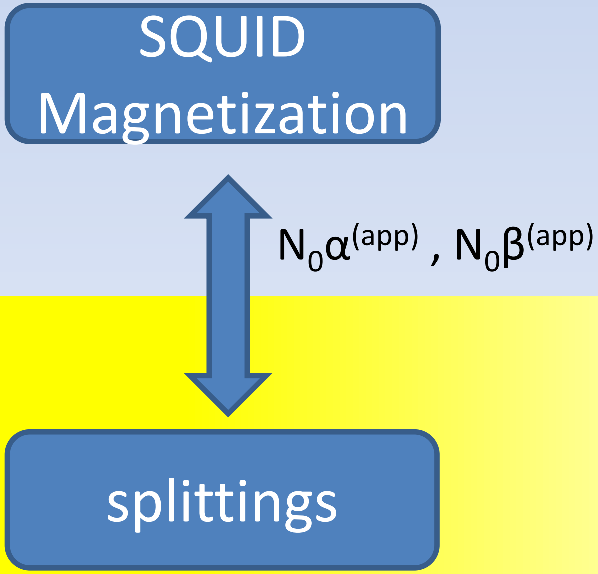
  - Straightforward interpretation of MCD, e.g., within a *rigid shift approximation*



- Wurztite structure DMS:
  - Three overlapping excitonic transitions
  - Mutually compensating excitonic contributions to MCD?



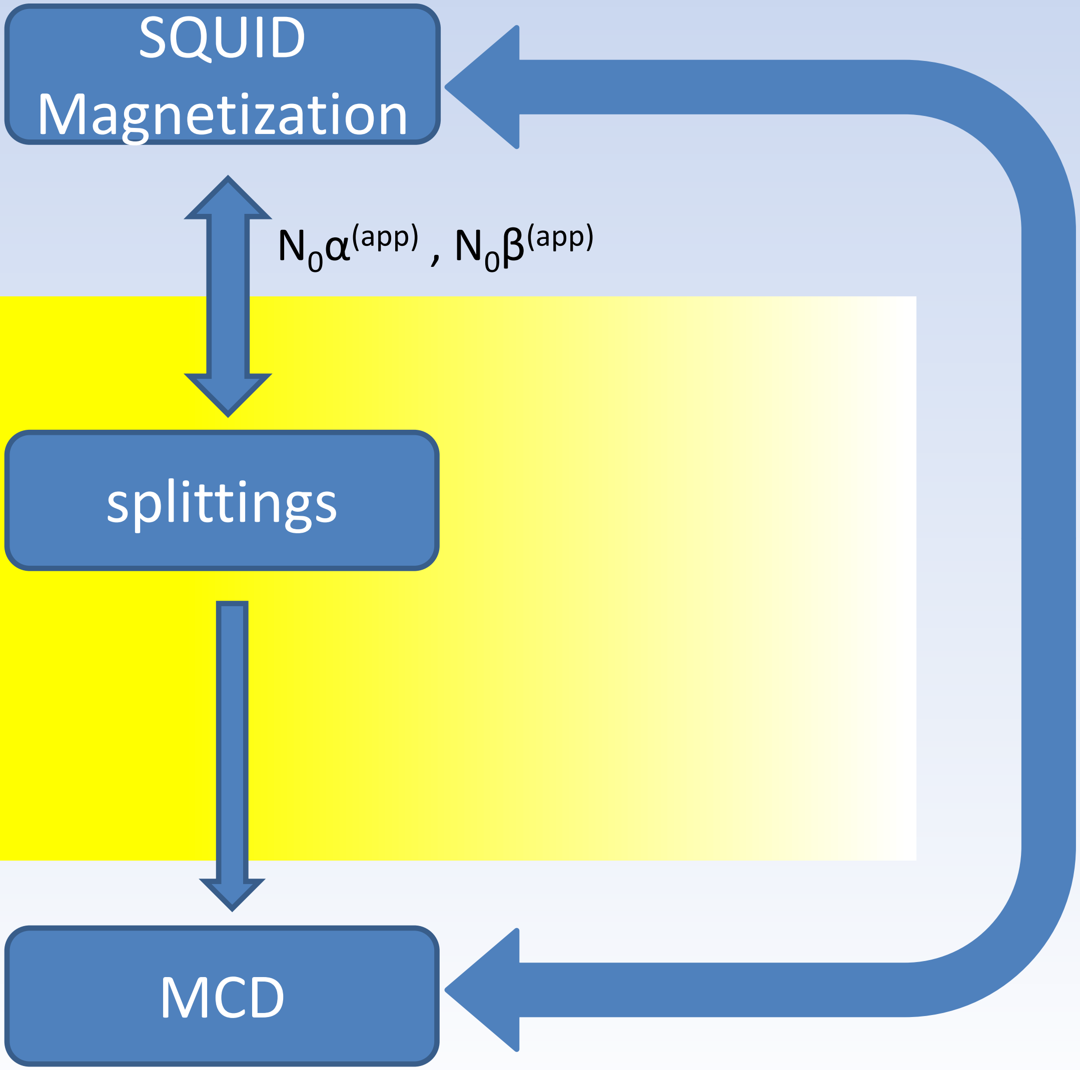
SQUID Magnetization

$N_0\alpha^{(app)}$, $N_0\beta^{(app)}$

splittings

A, B, C excitonic transitions

A, B, C excitonic transitions



SQUID Magnetization

$N_0\alpha^{(app)}$, $N_0\beta^{(app)}$

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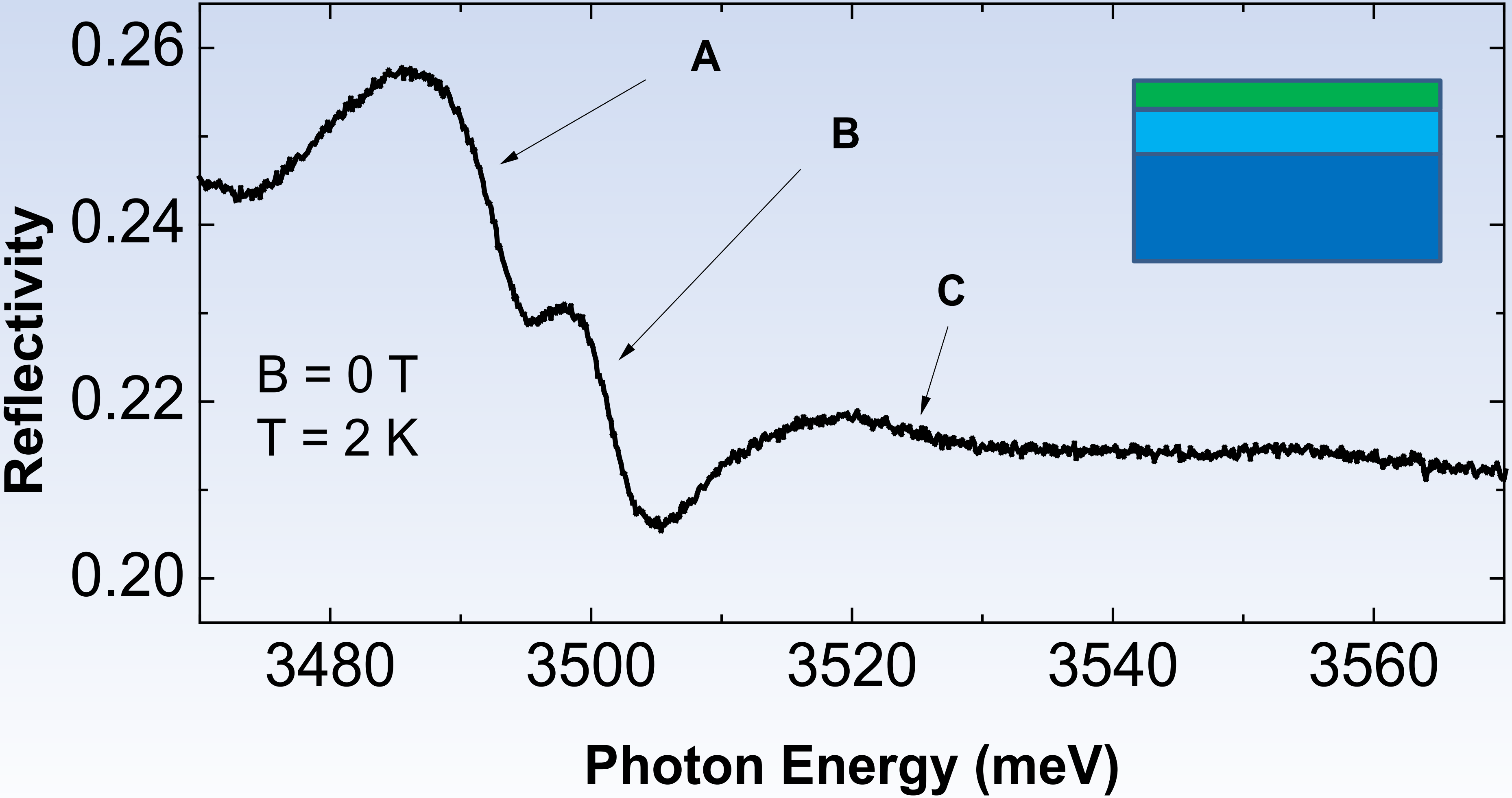
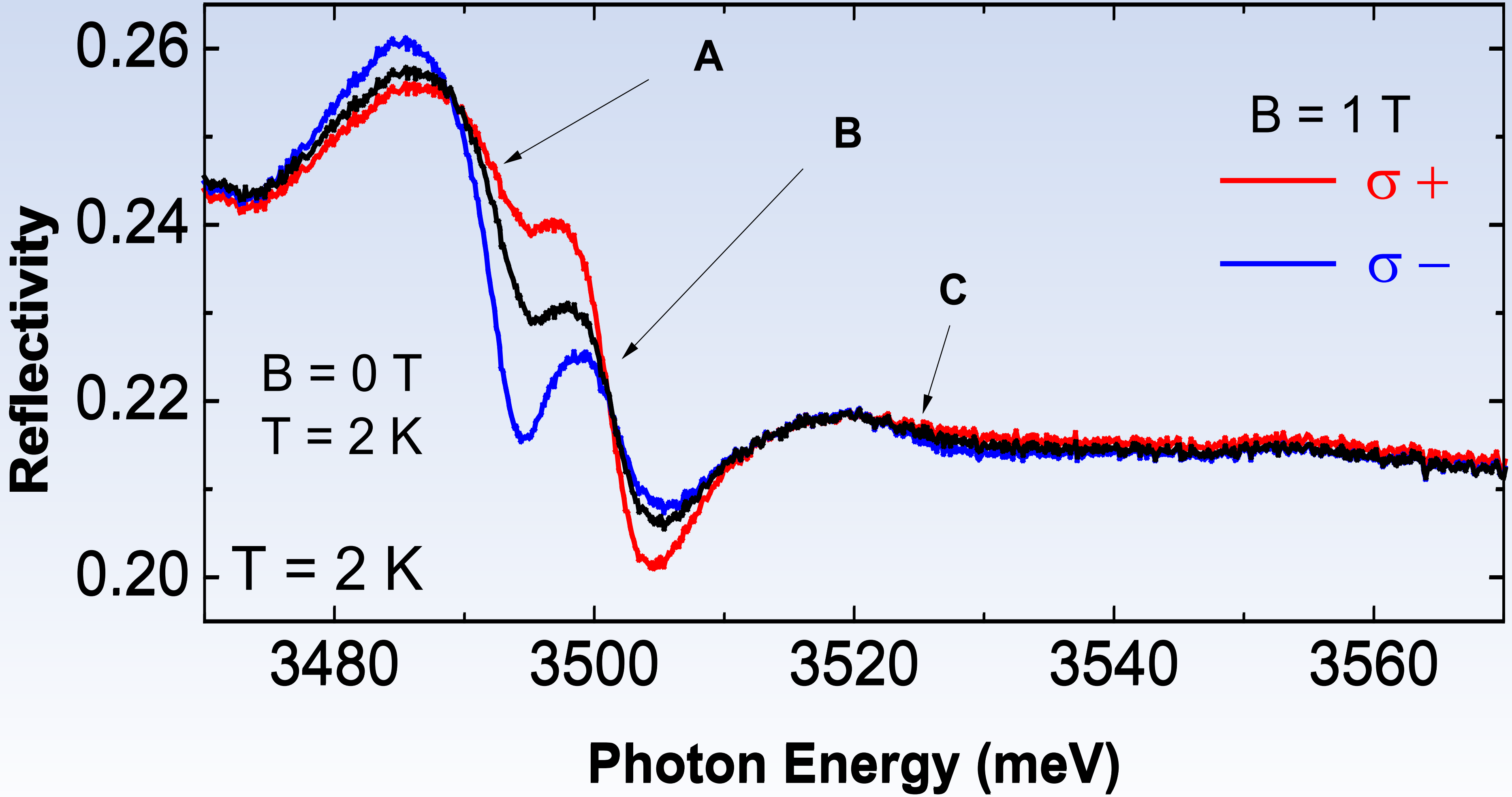
MCD

(Ga,Fe)N - near band gap reflectivity



(Ga,Fe)N - near band gap reflectivity



Modelling of the experimental spectra

Contributions to dielectric function ε(ω) from:

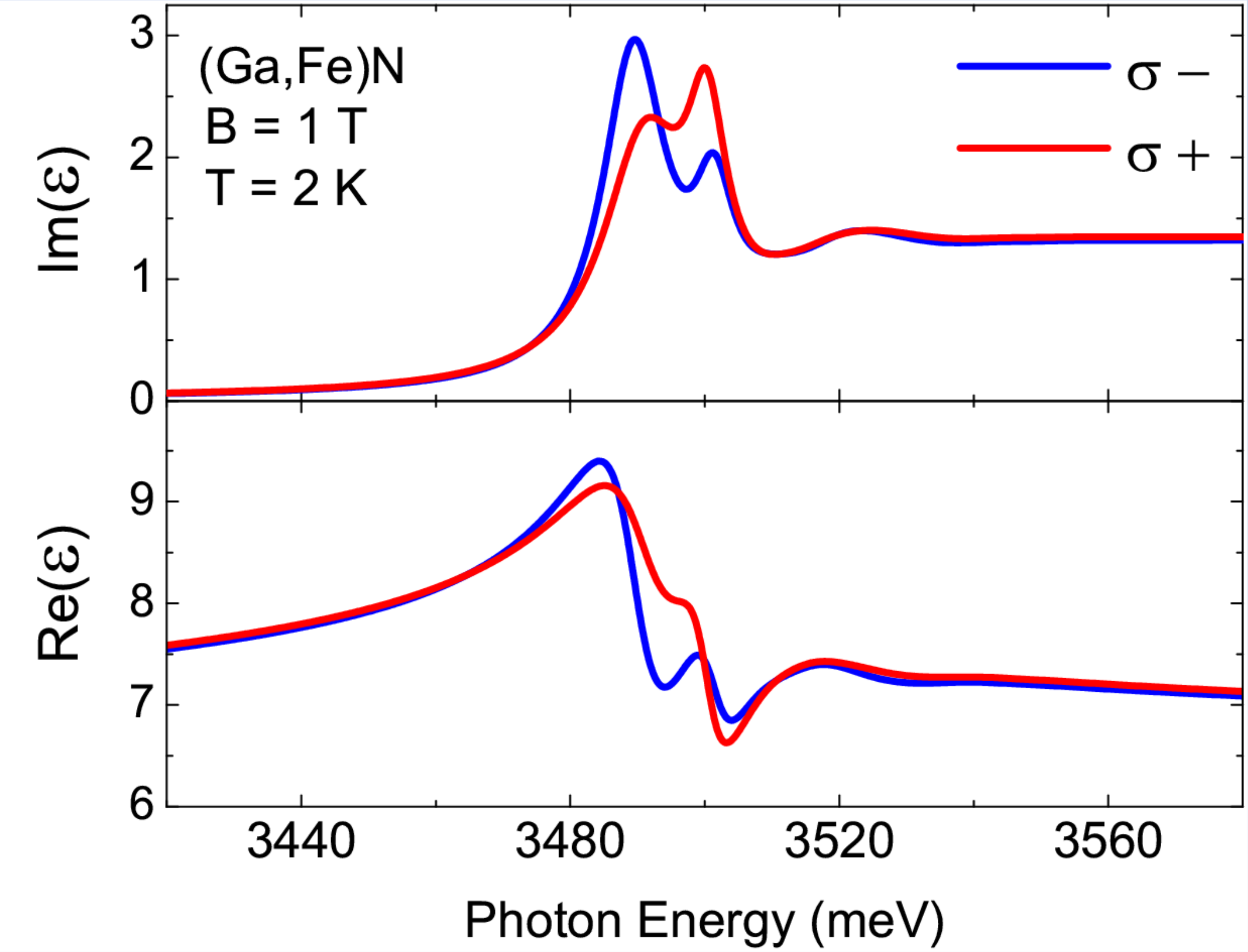
Fundamental A, B and C
excitonic transitions

Excited states of excitons

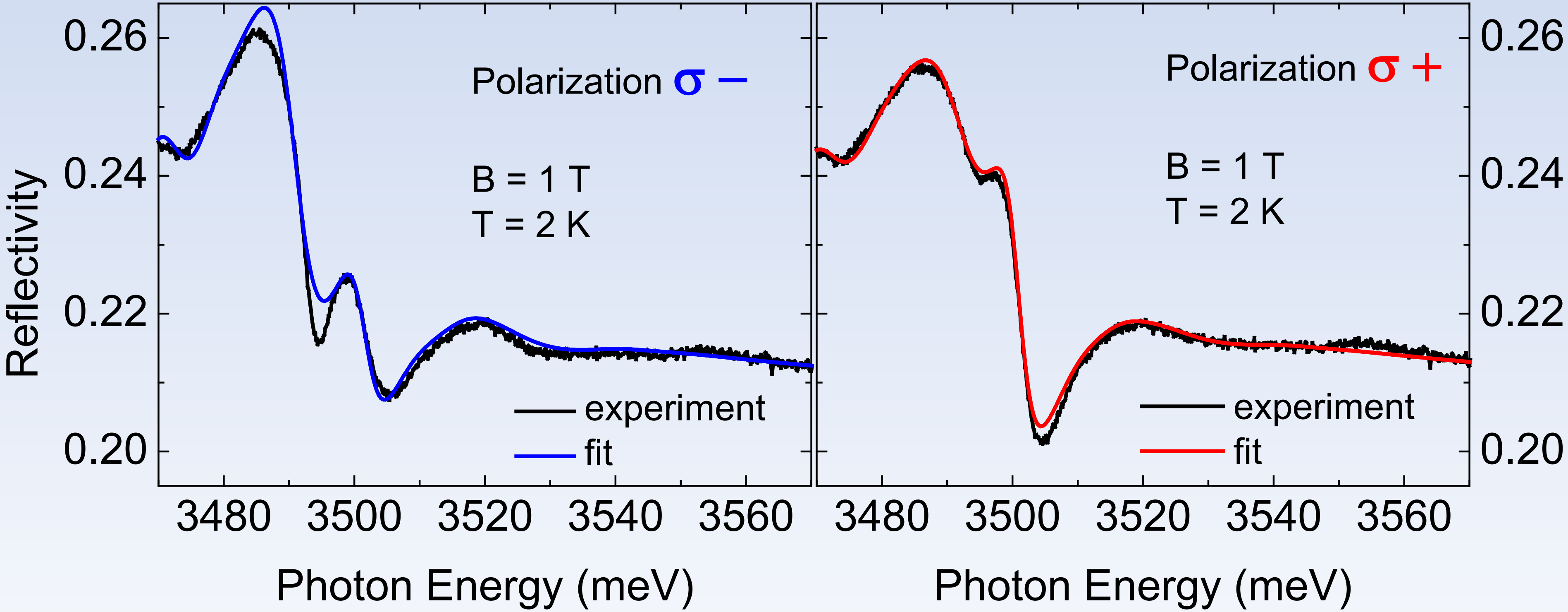
Unbound states

$$\varepsilon(\omega)= \varepsilon_0 + \sum_{n=A,B,C}\left(\frac{4\pi\alpha\alpha_{0,n}\omega_n}{\omega^2 n \quad -\omega^2 - i\omega\Gamma_n} + \sum_{j=2}^{\infty}\frac{4\pi\alpha\alpha_{0,n}\omega_{n,j}}{j^3}\frac{{\omega_{n,j}}^2}{{\omega_{n,j}}^2-\omega^2-i\omega\Gamma_{n,j}} + \varepsilon_{n,unbound}\right)$$

(Ga,Fe)N – dielectric function

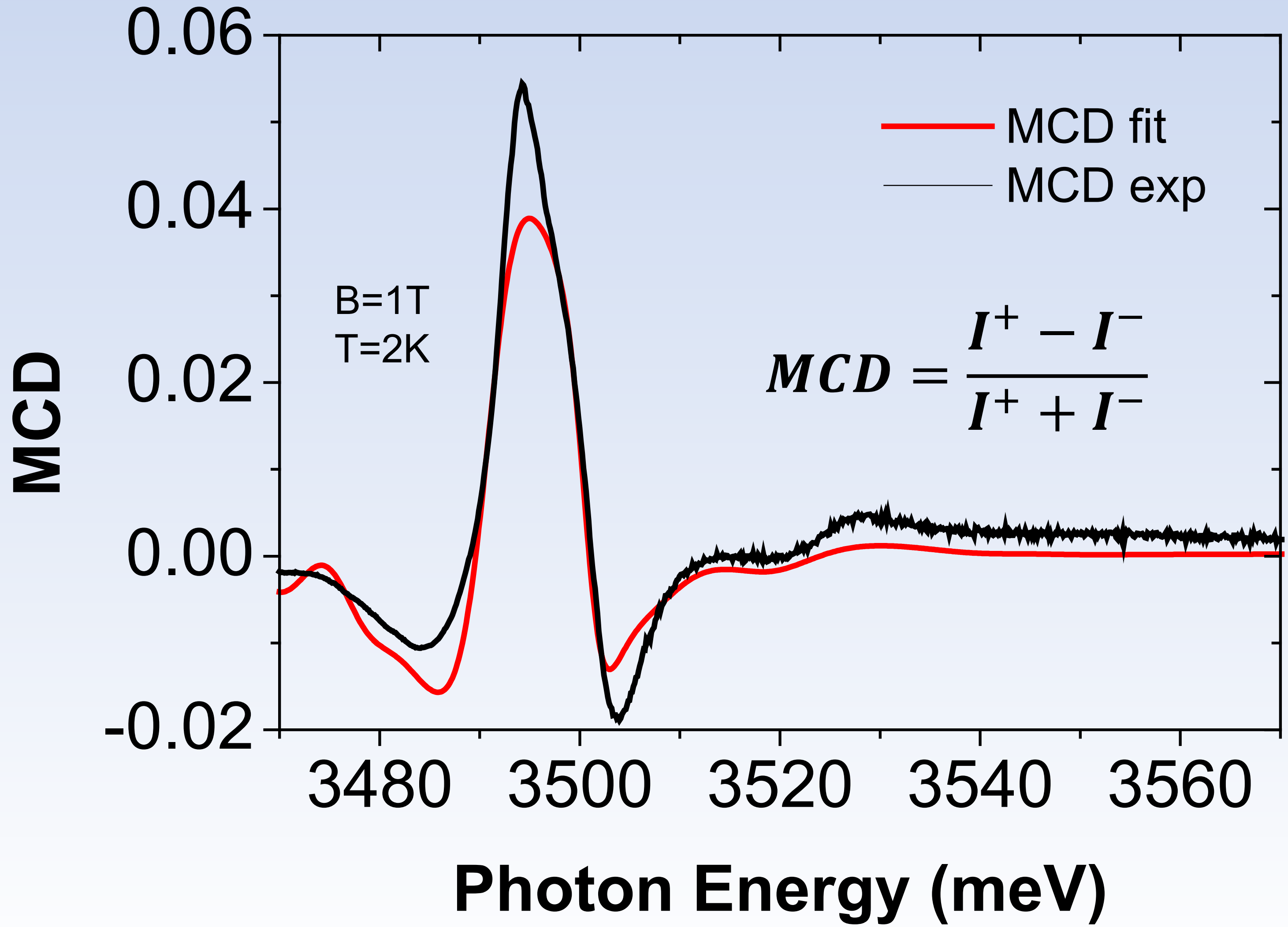


Reflectivity spectra



- A, B, C exciton parameters obtained from the model

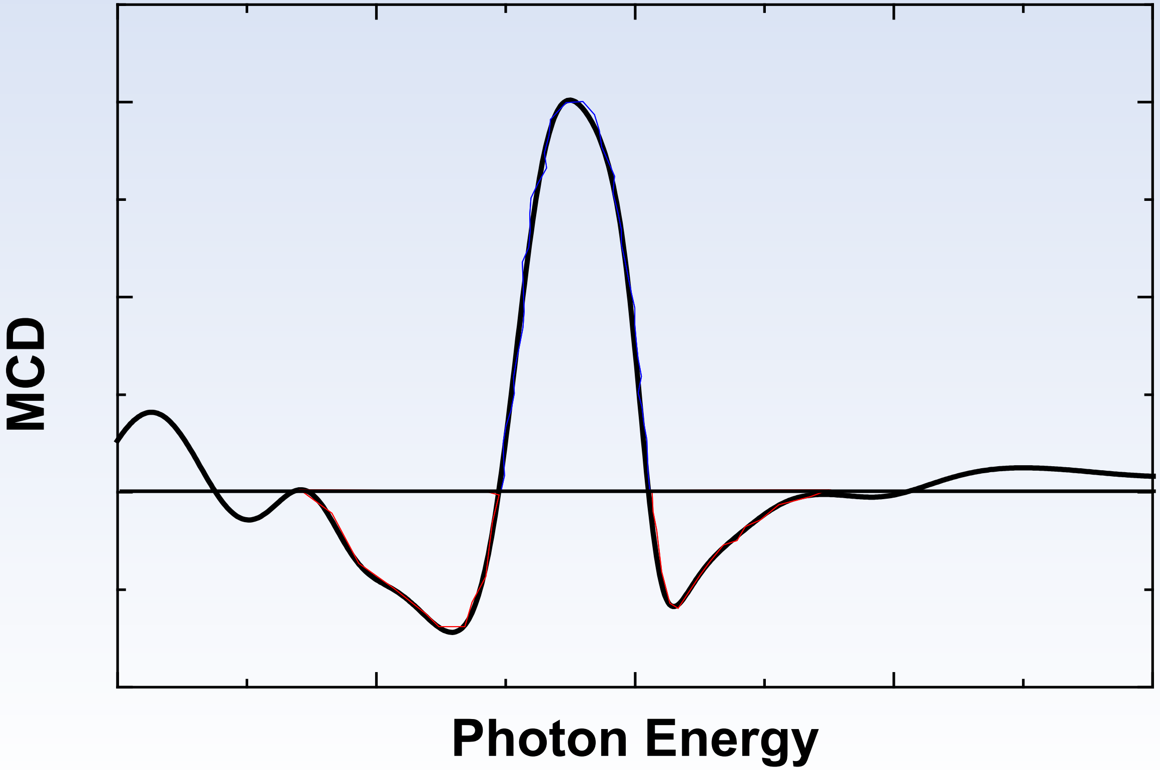
MCD based on experimental and fitted spectra



$$MCD = \frac{I^{+} - I^{-}}{I^{+} + I^{-}}$$

MCD and magnetization in (Ga,Fe)N

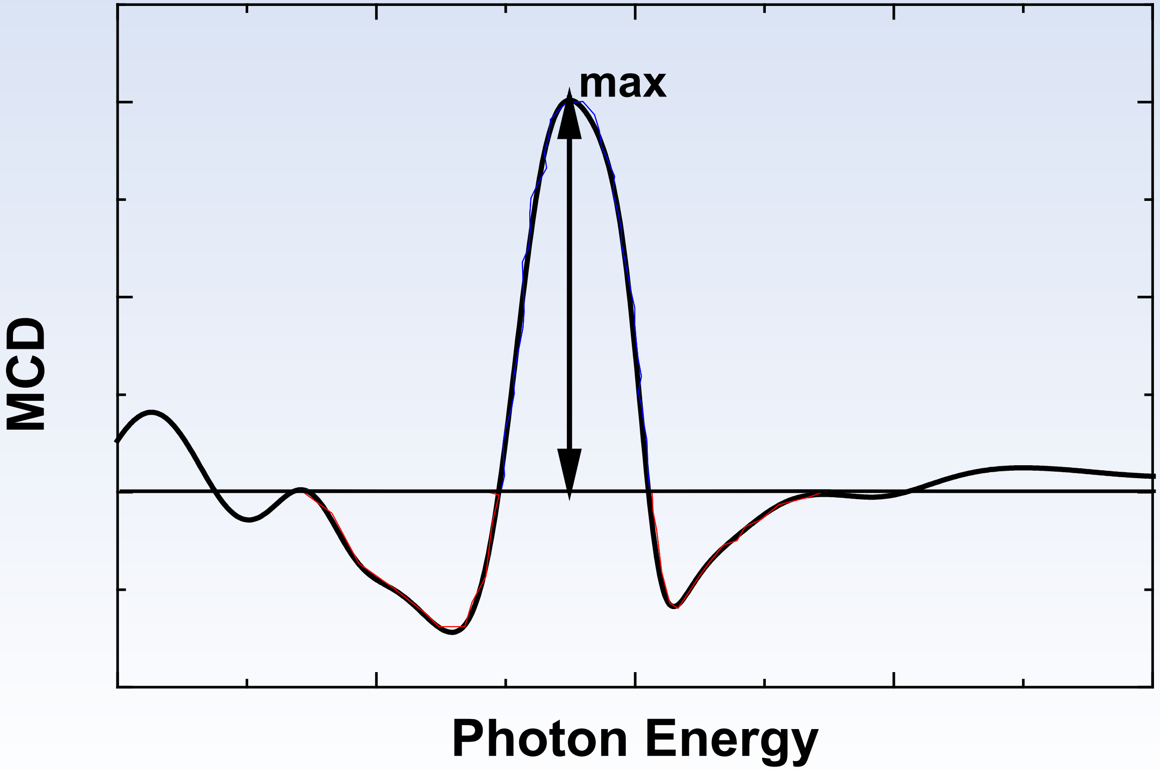
- How to quantify the magnitude of MCD?



- Integrated absolute area

MCD and magnetization

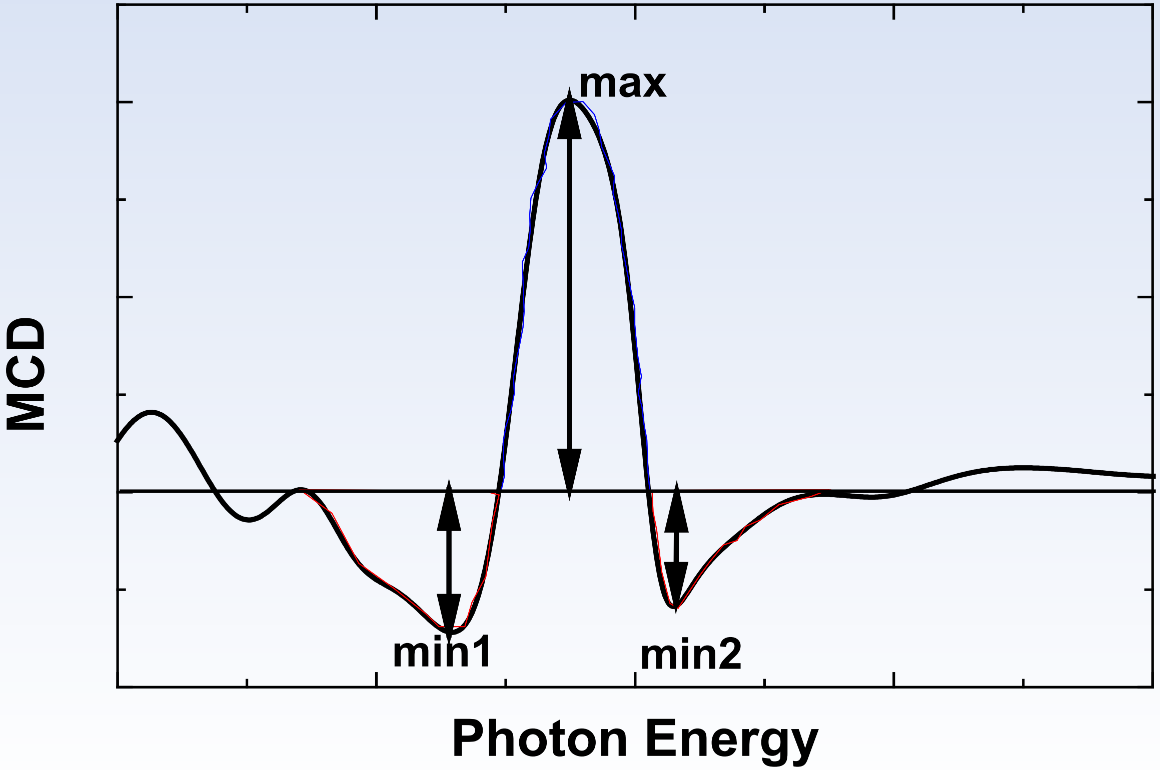
- How to quantify the magnitude of MCD?



- Integrated absolute area
- Amplitude (max)?

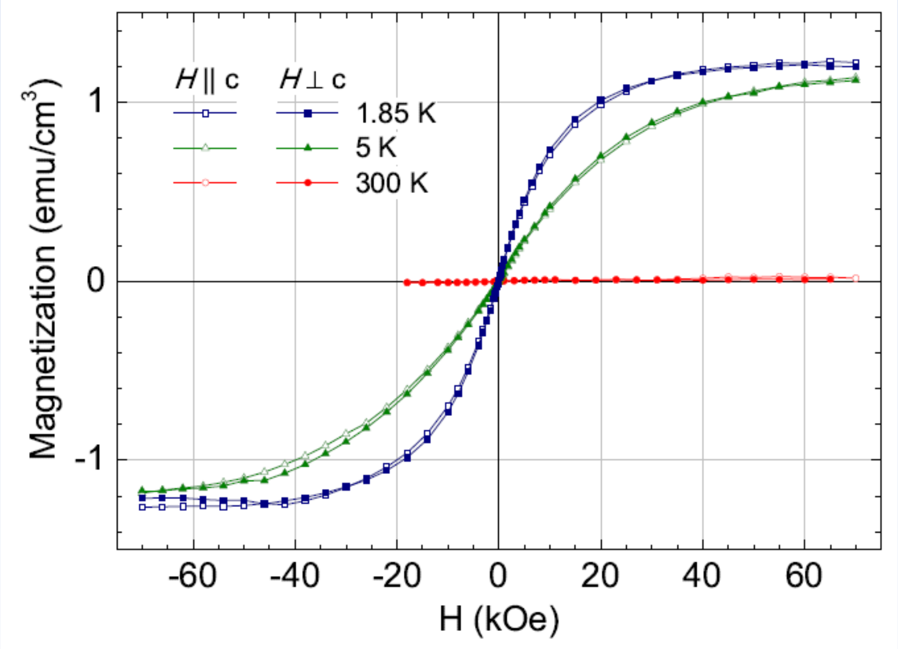
MCD and magnetization

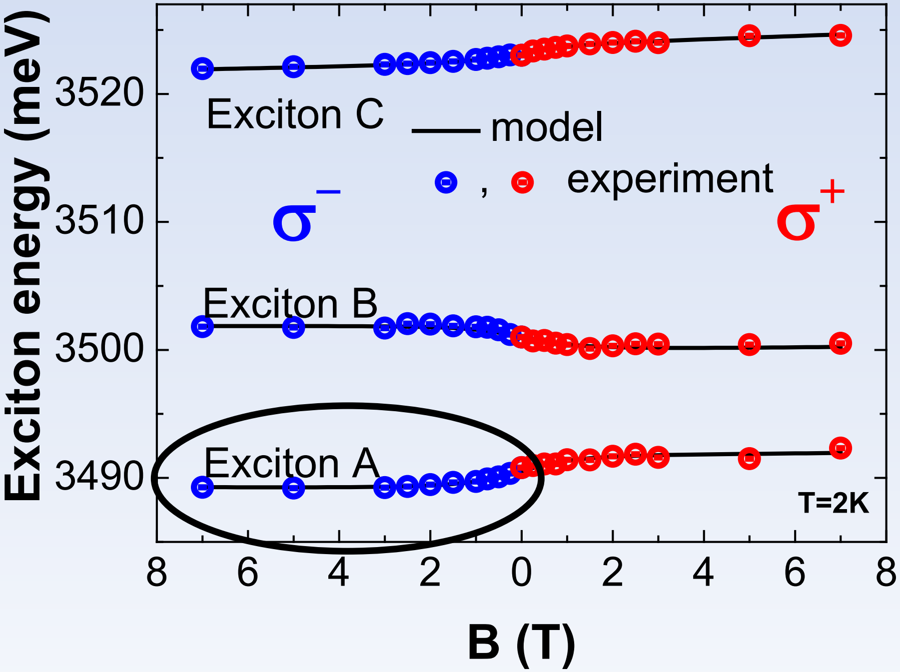
- How to quantify the magnitude of MCD?



- Integrated absolute area
- Amplitude (max)?
- Sum of extrema (max – min1 – min2)?

Magnetization and excitonic splittings

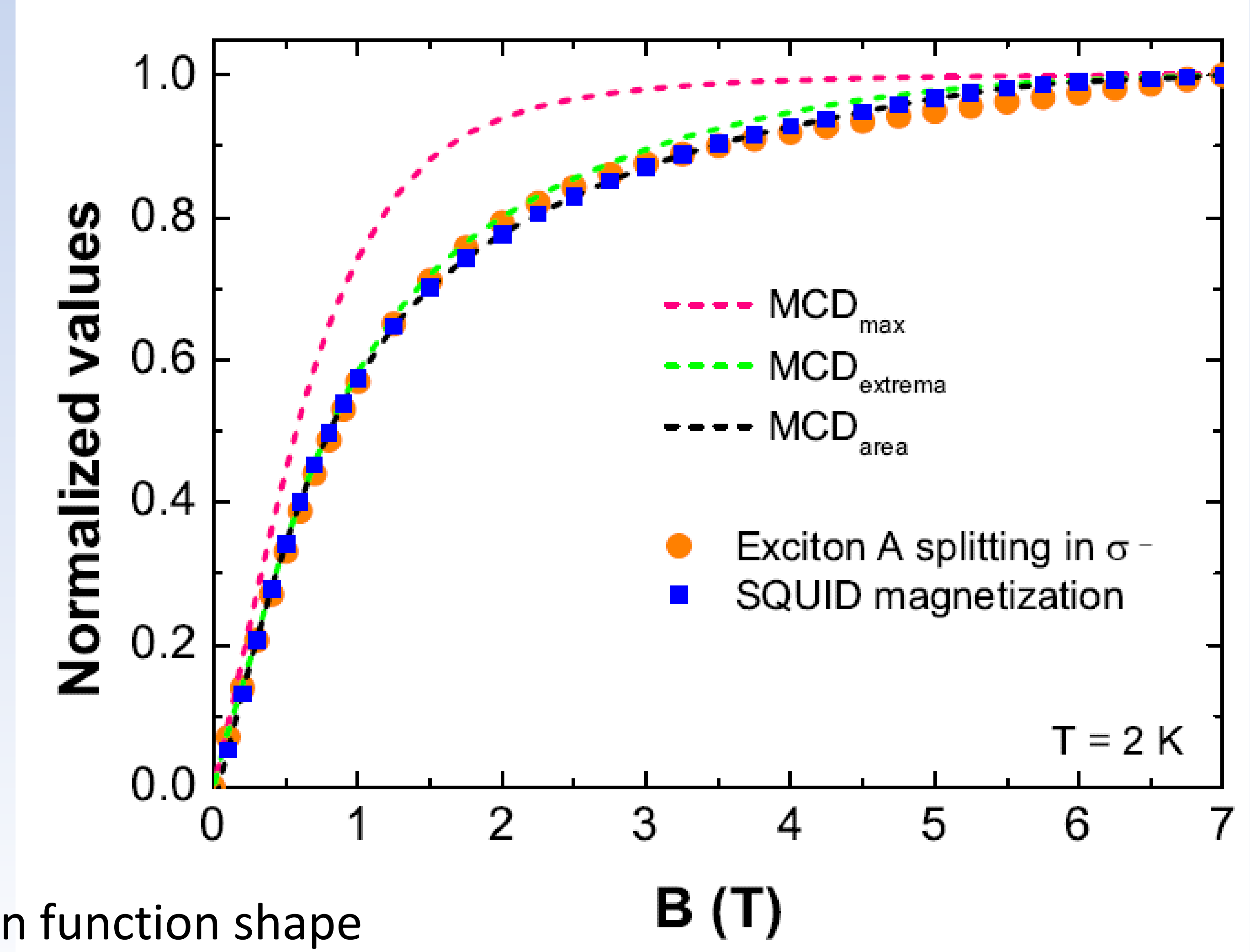




SQUID magnetization

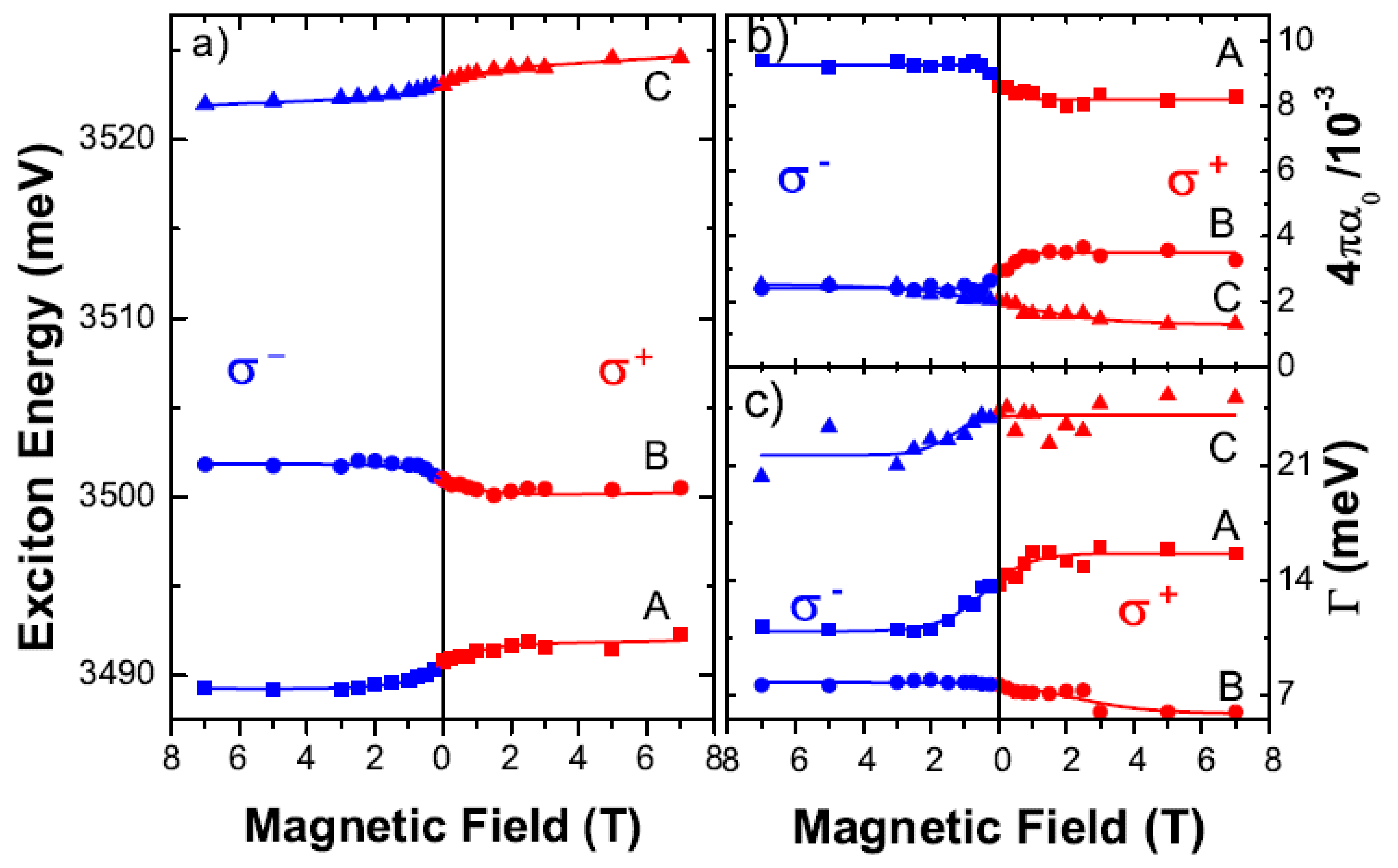
Excitonic splittings

Excitonic splitting, MCD and magnetization



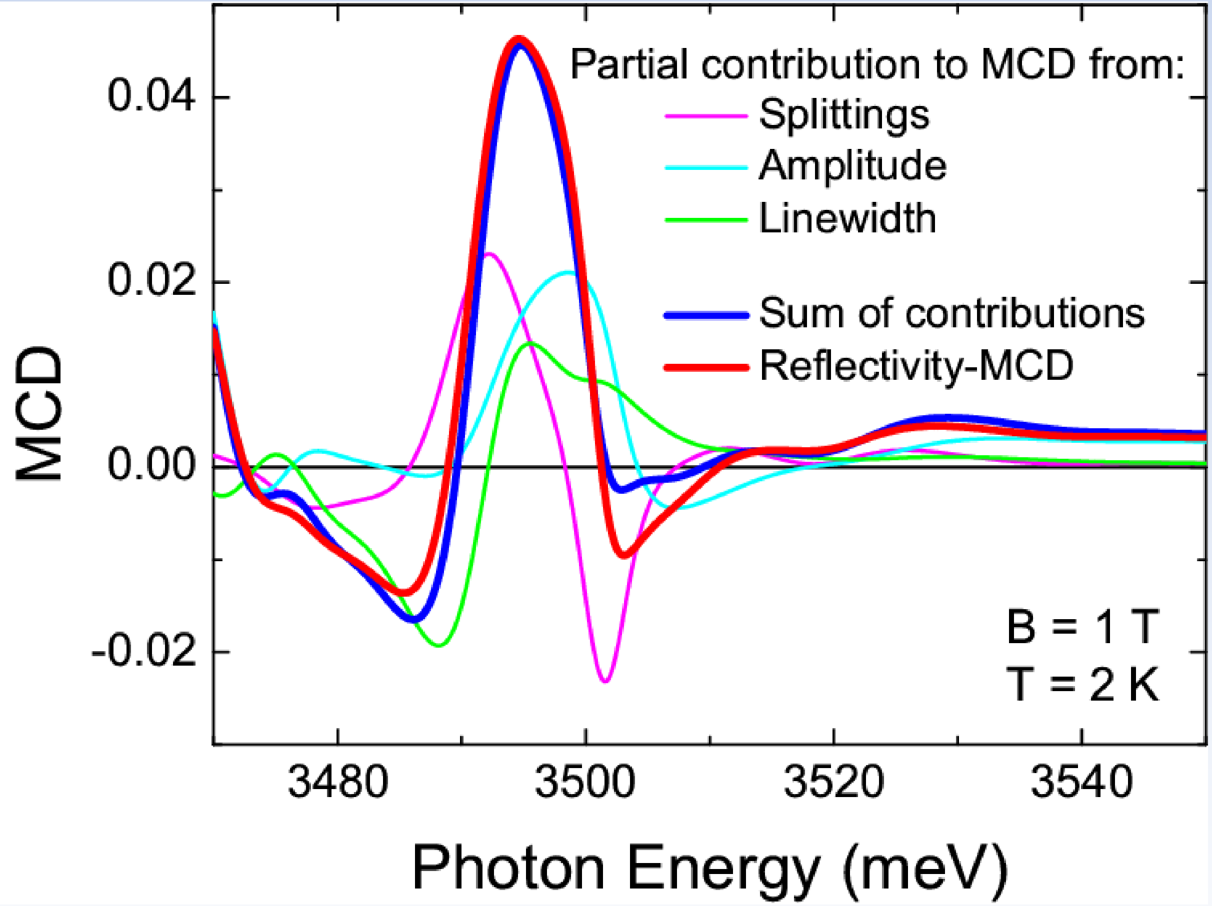
- Brillouin function shape
- Good agreement between magnetization determined from magnetometry and magnetooptics (exciton A splitting and MCD integrated absolute area)

Exciton parameters in magnetic field



- Exciton oscillator strength, linewidth and splitting modified by the magnetic field

Contributions to MCD from exciton oscillator strength, linewidth and splitting



- Partial contributions to MCD of comparable weights
- Splitting deduced from MCD - overestimated

Conclusions I

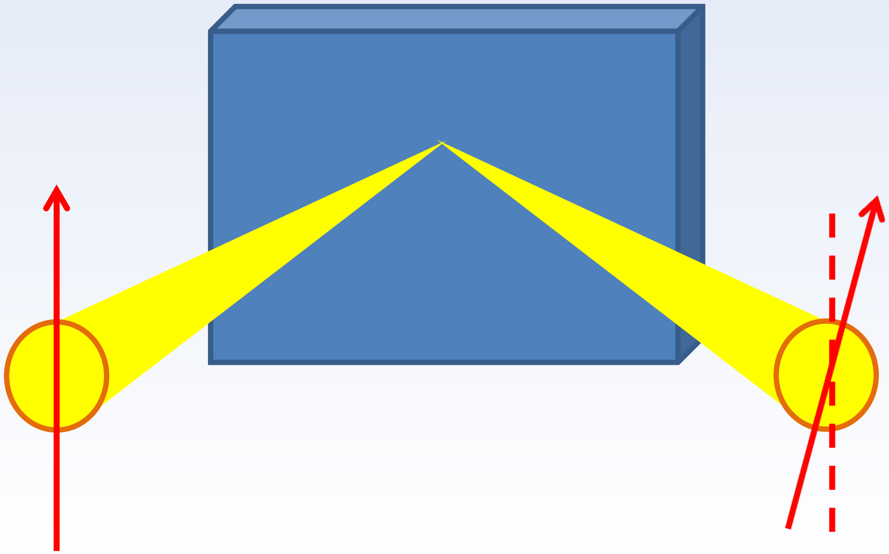
- Excitonic splitting proportional to magnetization as in zinc-blende DMS
- Correct description of the magnetization by the MCD (□integrated absolute area under the MCD curve)
- Variations of all three excitonic lines parameters (splitting, linewidth, oscillator strength) contribute to the MCD signal with comparable weights

J.-G. Rousset *et al*., Phys. Rev. B, in print

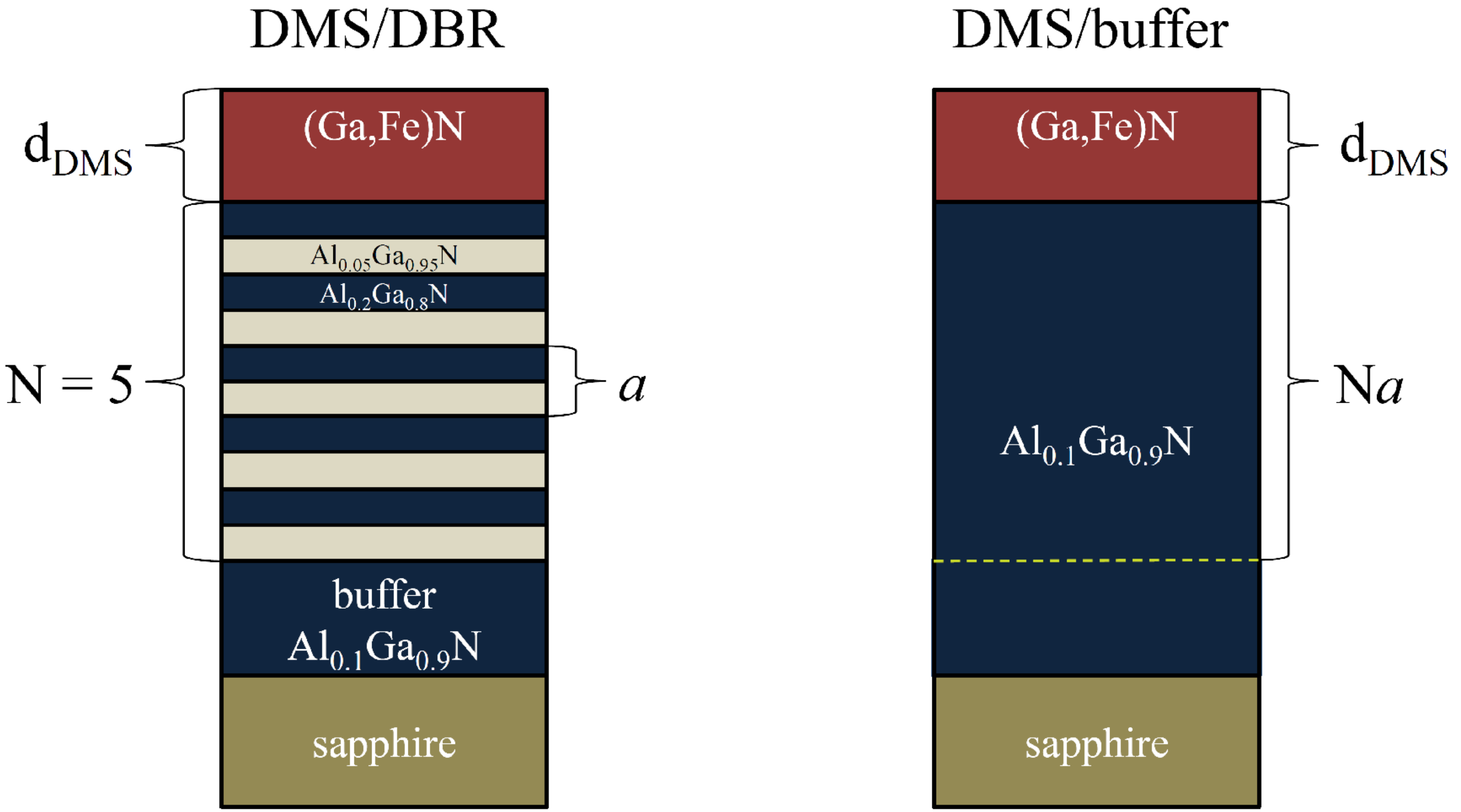
Magneto-optical Kerr effect

- Arises from the difference between optical absorption or reflectivity of left and right circular polarized light
- Quantified as:

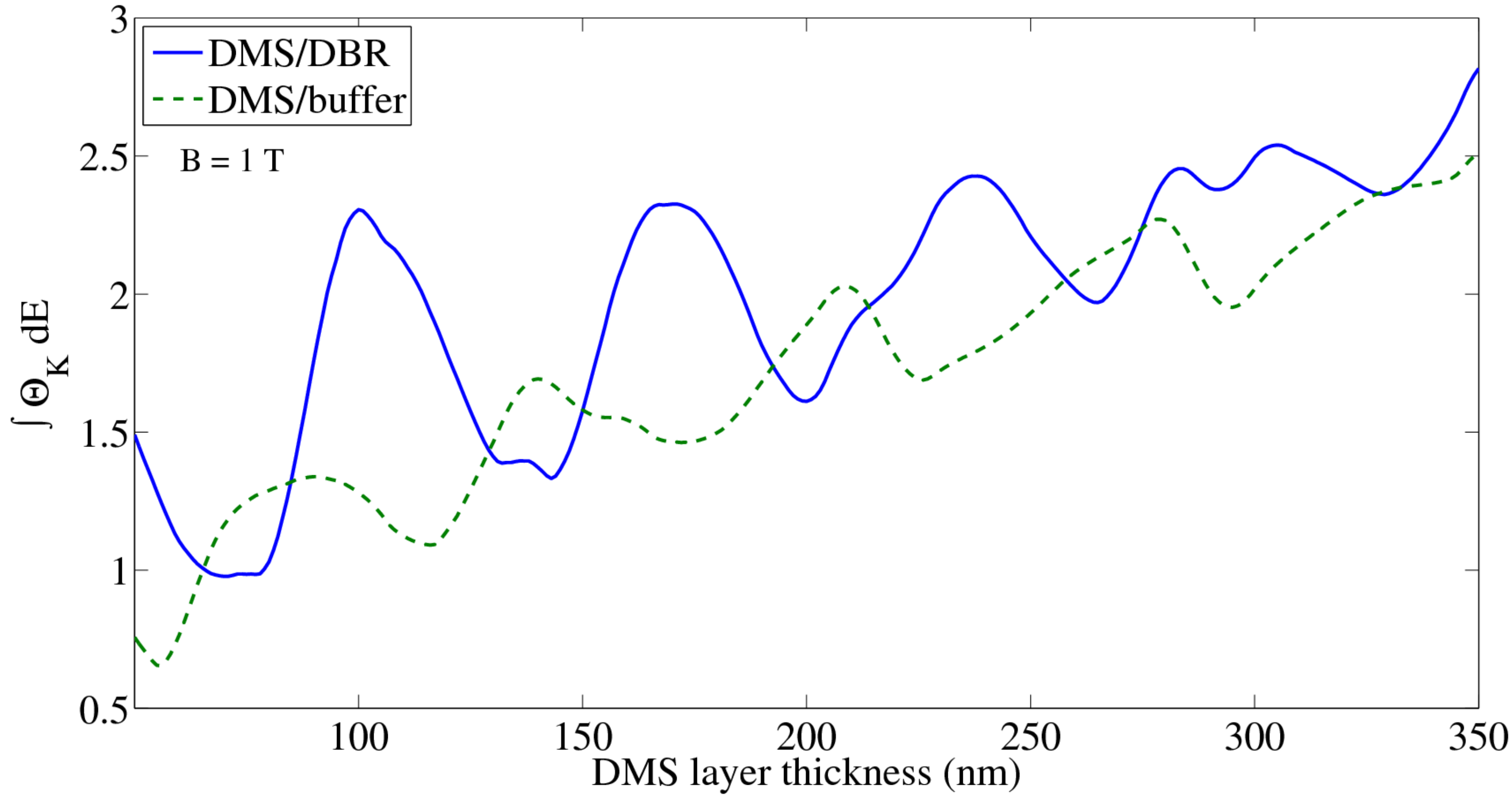
$$\Theta_K = \frac{1}{2} \arg \frac{r^-}{r^+}$$



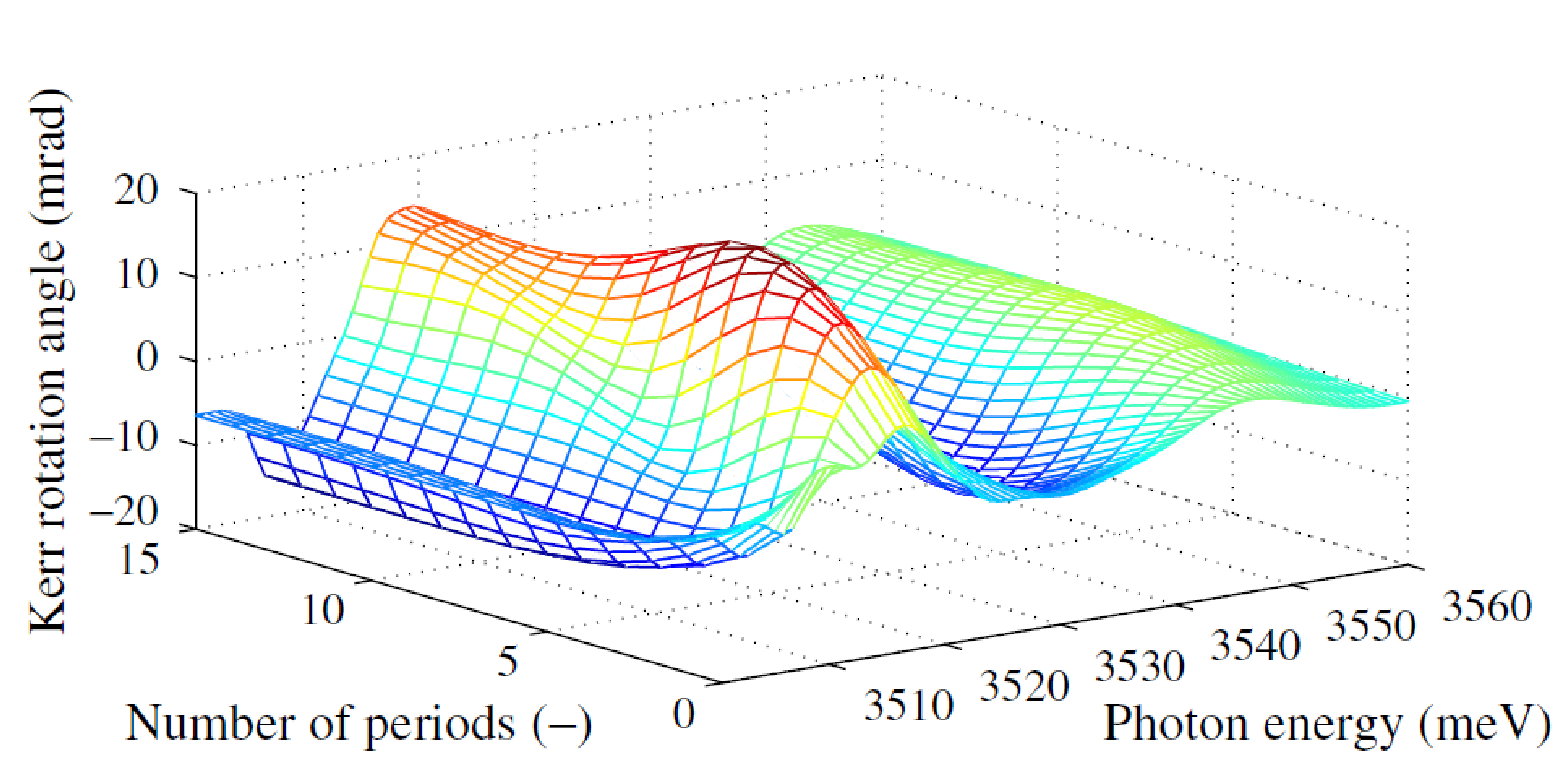
Sample design



Impact of a sample design: DMS thickness

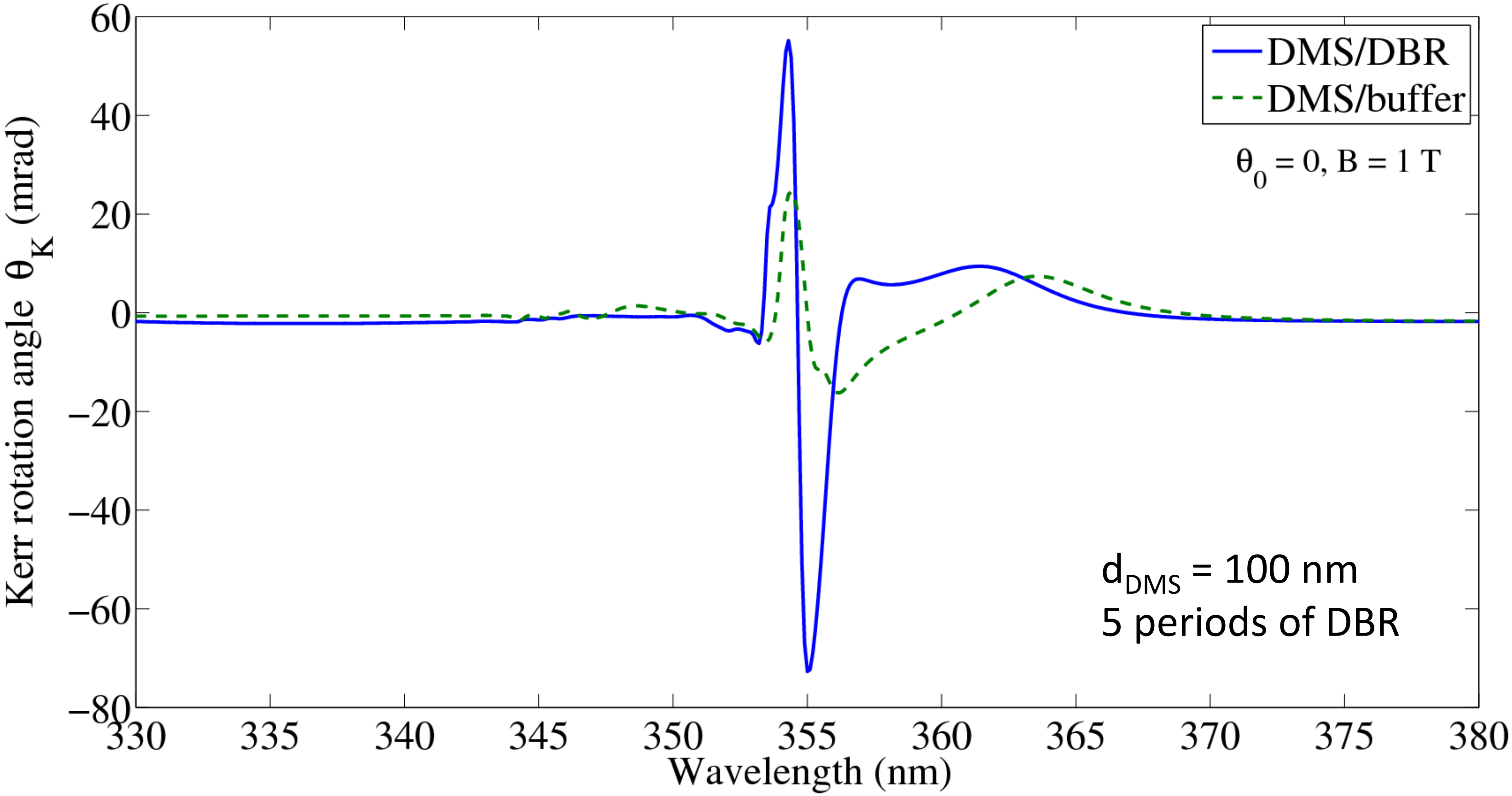


Impact of a sample design: DBR quality



- Already small number of periods of DBR mirror enough to enhance MOKE

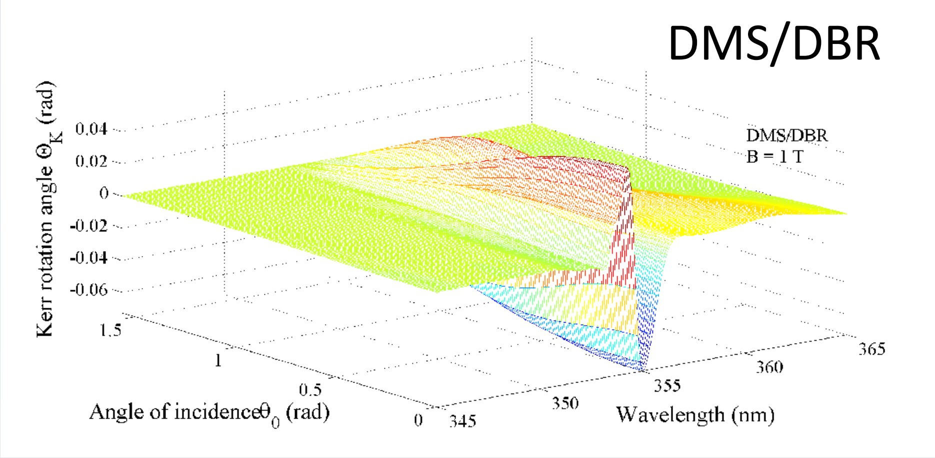
Normal light incidence case

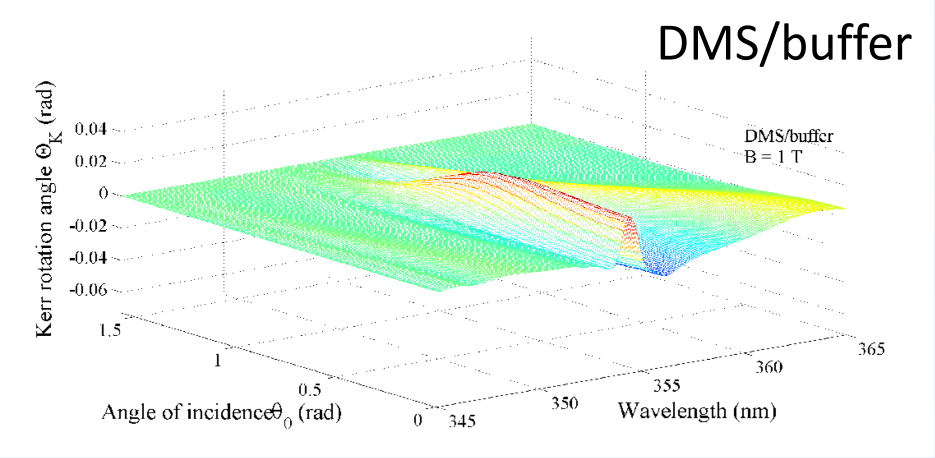


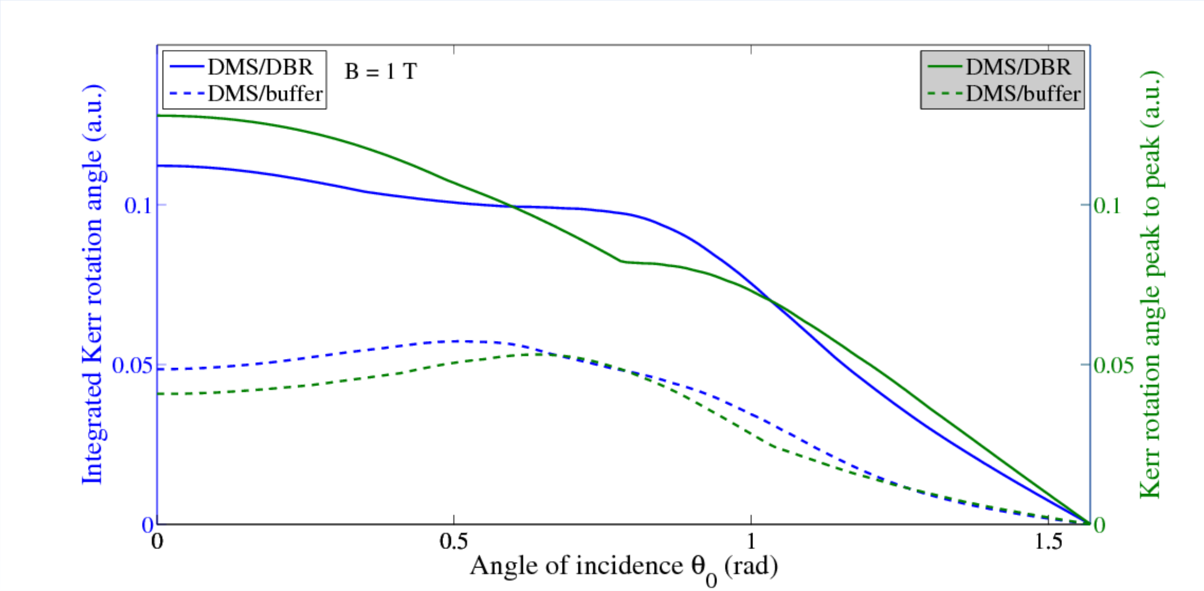
d_{DMS} = 100 nm
5 periods of DBR

- Bragg mirror placed undreneath the DMS layer significantly amplifies MOKE

Angle dependencies: TE polarization

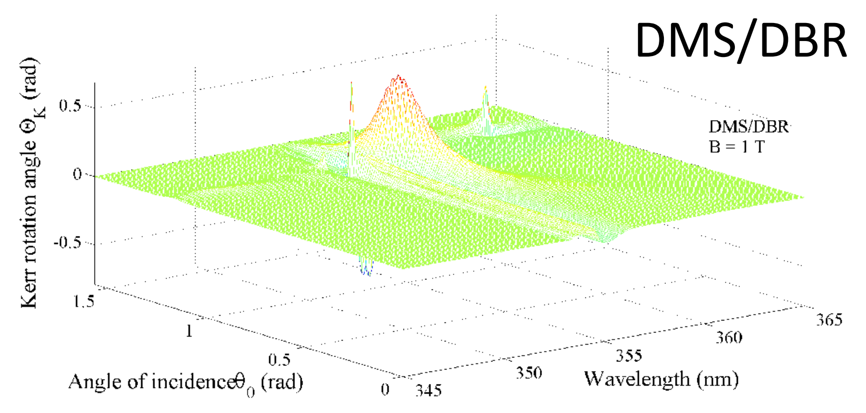

DMS/DBR

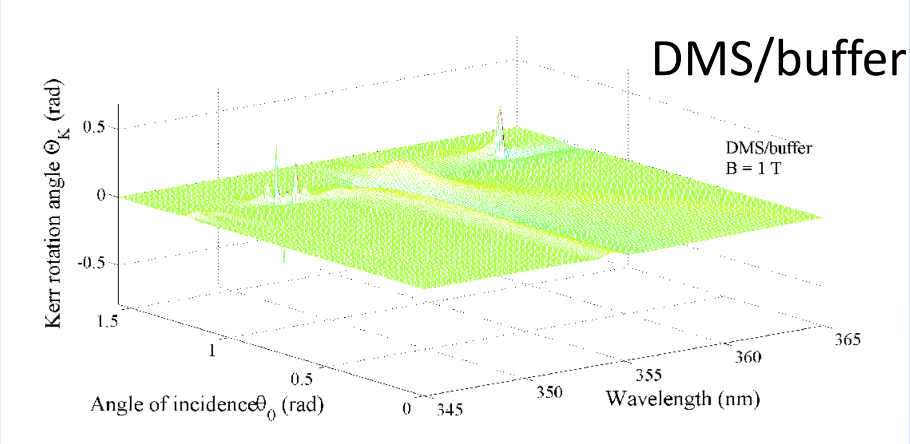

DMS/buffer

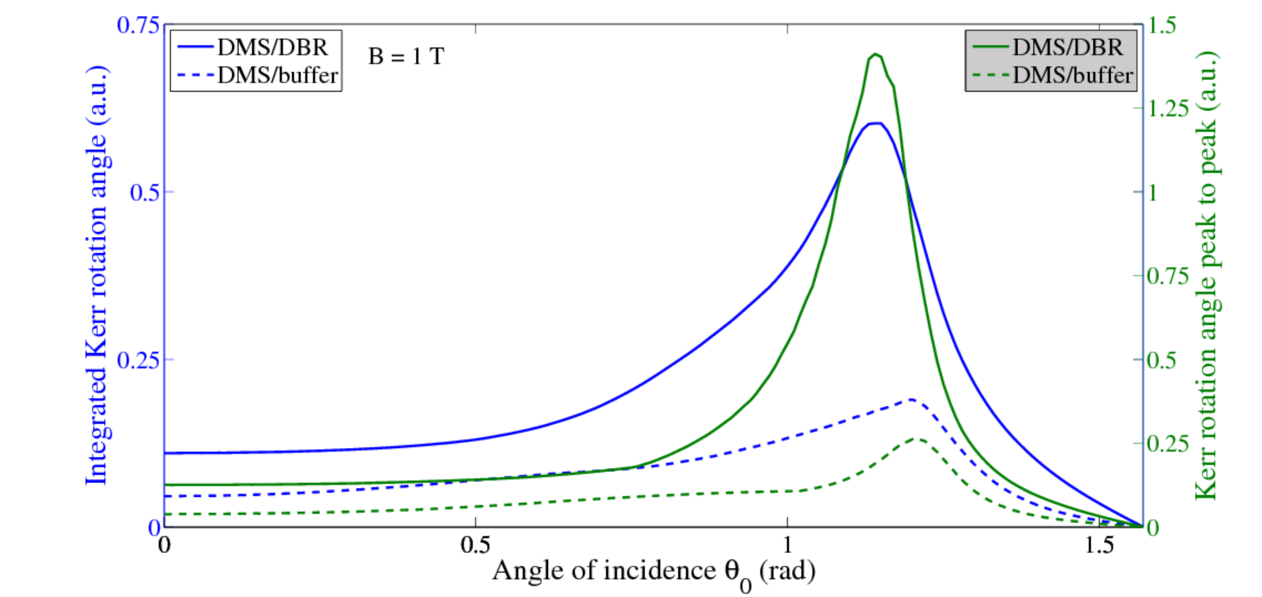


- MOKE enhancement maintained at wide incidence angle range

Angle dependencies: TM polarization


DMS/DBR


DMS/buffer



- Very strong enhancement of MOKE at Brewster incidence angle

Conclusions (II)

- Magnitude of the MOKE in DMS depends on the actual sample design, e. g., thickness of the DMS layer

- Significant amplication of MOKE thanks to a relatively small number of periods of DBR mirror placed underneath the DMS layer

- The enhancement maintained for a wide range of the light incidence angles

- The maximum enhancement of the MOKE is obtained for the TM polarized light incidenting at Brewster angle

M.Koba and J.Suffczyński, Journal of Electromagnetic Waves and Applications 27, 700 (2013).