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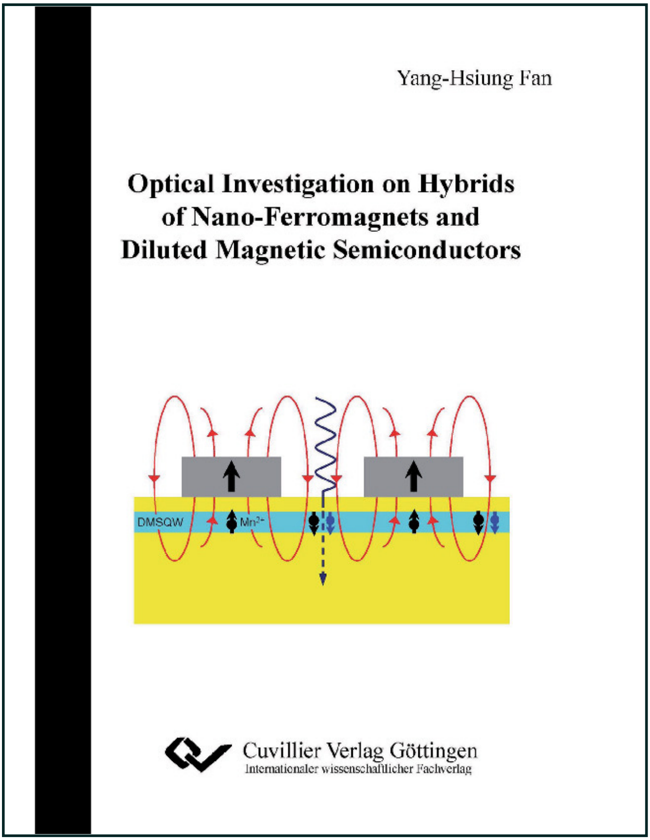
Optical Investigation on Hybrids of Nano-Ferromagnets and Diluted Magnetic Semiconductors



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Chapter 1

Introduction

The conventional electronic devices are designed to control the charged carriers via electrical gates. Currently, innovative devices using spin for information processing are considered which offer one possibility for realizing Quantum Computing [1, 2]. Thanks to the molecular beam epitaxy (MBE) growth method, nowadays semiconductor can be designed precisely to meet the requirements of different devices. To control spin, micro magnet with controllable field direction should be used in analogy to the gates used to control charge.

Diluted magnetic semiconductor (DMS) offers an outstanding potential to study magneto-optical properties especially for excitons near band edge. The paramagnetic ions Mn^{2+} in DMS reveal a strong giant Zeeman effect and giant Faraday effect via s,p-d exchange interaction between localized Mn^{2+} 3d electrons and carriers of semiconductor [3]. Additional interactions such as crystal field, strain, and quantum confinement can be inspected more easier in external magnetic field.

There are already some interesting steps in the direction of spintronics [4] just like the spin injection into the Semiconductor (SC) [5–8] or the manipulation of the spin from resident and/or photo-excited carriers in the SC [9, 10]. Polarized photoluminescence (PL) and Faraday rotation (FR) techniques are applied to study these effects.

First goal of this study is the investigation of a hybrid structure made of a ferromagnetic layer (FM) on the top of a DMS to control the Mn and carrier spin in a gate-like way. To assure constant distance between FM and carriers a DMS quantum well with a cap layer of defined thickness is used. Quantum confinement and strain lead to a splitting of the sub-valence band in the Brillouin zone center with the heavy-hole subband as the uppermost one. Since this hole has only a magnetic moment along growth direction, a FM with out-of-plane magnetization has to be used. For the DMS, ZnSe-based heterostructures are used, the magneto-optical properties are well studied in literatures [11, 12].

In addition, ZnO-based DMS are chosen to study their s,p-d interaction according to promising theoretical predictions [13, 14]. ZnO has the band gap transitions in the UV region. So far, the s,p-d constants have been experimentally figured out on $Zn_{1-x}Co_xO$ epilayers [15] and p-type $Zn_{1-x}Mn_xO$ made by oxidation $Zn_{1-x}Mn_xTe$ layers [16]. Surprisingly, values of p-d interaction much smaller than those in ZnSe- and CdTe-based DMS are found.

After this introduction (Chapter 1), the main work is summarized in the following chapters. At the beginning, the theoretical aspects of studied ZnSe- and ZnO-based DMS are given. The crystal structure, the structure of conduction as well as valence band, and specific properties of heterostructures are described schematically. Interactions responsible for energy shifts of the excitons are classified thematically. The significant s,p-d exchange interaction is considered in detail. The circular polarization of the optical transitions is discussed.

Studied samples and applied experimental techniques are illustrated in Chapter 3. Sample designs are listed in tabular form. Different samples of quantum well (QW) and epilayer structures are drawn schematically for comparison. Measurement setups for PL, reflectivity, and Faraday rotation are sketched.

In Chapter 4, the studied samples are characterized at first to ensure the sample properties such as huge g-factor and distinct PL. The heating measurement shows the magnetic-field dependent and photo-excitation flux-dependent energy shifts of excitons. The fringe fields of FM nanostructures is studied both by polarization degree of PL as well as by Faraday rotation. Erasing and reversal of FM magnetization using a single laser pulse is demonstrated finally for the DMS-FM hybrid structure.

Finally, ZnO-based semiconductors are studied to determine the s,p-d exchange integrals $N_o\alpha$ and $N_o\beta$. Reflection spectra of non-magnetic ZnO- and semimagnetic $Zn_{1-x}Mn_xO$-epilayers ($x = 0.41\%$ and 0.78%) are measured. The Mn-concentration dependence of exciton energies shows the constant splitting Δ_{so} between A- and B-exciton resonance. To estimate exchange integrals, the usual Zeeman splitting and the electron-hole exchange interaction should be included in the data analysis. The obtained modulus $N_o \mid \alpha - \beta \mid = 0.25$ eV is responsible for the splitting of the optical allowed $\sigma^{\pm}$ polarized exciton transitions. It shows that this material is much less appropriate for hybrid structure compared to (Zn,Cd,Mn)Se DMSQW with $N_o \mid \alpha - \beta \mid \approx 1.5$ eV.