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TE- and TM-polarization-resolved spectroscopy on quantum wells under normal incidence

M. Schardt[a,b,*], A. Winkler[a,b], G. Rurimo[b], M. Hanson[c], D. Driscoll[c], S. Quabis[b], S. Malzer[a,b], G. Leuchs[b], G.H. Döhler[a,b], A.C. Gossard[c]

[a] *Institute for Technical Physics I, University of Erlangen-Nuremberg, Germany*
[b] *Max-Planck Research Group, Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Germany*
[c] *Materials Department, University of California, Santa Barbara, CA 93116, USA*

Abstract

We present TE- and TM-polarization-resolved photocurrent measurements on quantum well pin diodes under normal incidence. Usually, optical experiments performed in such a geometry yield information only about transitions involving in-plane (p_x and p_y) components of the hole wave functions because of the in-plane (TE) polarization of the light. Information on transitions sensitive to the p_z components can be obtained by focussing a radially polarized laser beam through a microscope objective with high numerical aperture (NA = 0.9). With our setup, the electrical field vector at the focal tail has a significant component along the optical axis (TM-polarization!) which enables excitation of transitions sensitive to p_z components also. Additionally, the existence of a degenerate (azimuthally polarized) optical mode enables switching these p_z components on and off easily.

Experimental evidence of these features has been achieved by exploiting the selection rules for e–hh and e–lh transitions in a quantum well structure. We present a comparison of our recorded spectra with theoretical predictions obtained from simple geometric optics assumptions. For our quantum wells the polarization effects are small because our measurement averages the intensity distribution of the whole focal plane. We plan to extend our measurements to polarization resolved single quantum dot spectroscopy. By restricting the detection region to the spatial extent of a single dot, one can exploit the almost pure TM-polarization on the optical axis for obtaining high contrast between heavy- and light-hole exciton absorption.

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Keywords: Quantum wells; TE-polarization; TM-polarization; Spectroscopy

1. Radially and azimuthally polarized light beams

Spectroscopy under normal incidence usually does not allow for adjusting the polarization to be perpendicular to the sample surface (TM-polarization) but is purely TE-polarized. Focussing a radially polarized laser beam through a microscope with high numerical aperture (NA = 0.9, e.g.), however, allows to extract information also regarding the TM-polarization.

The preparation of a radially polarized beam is schematically depicted in Fig. 1.

The linear polarized beam of a laser source is collimated and converted into radial or azimuthal polarization by a polarization converter. A non-confocal Fabry–Perot interferometer is used as a mode filter. The output of this system is a donut-shaped optical mode with radial (or azimuthal) polarization.

The basic concept of the polarization converter is shown in Fig. 2.

The polarization converter is made up of $\lambda/2$-plates arranged as a "cake" with the major axes oriented as indicated. For each segment, the electrical field vector is mirrored at the major axis of the corresponding $\lambda/2$-plate.

*Corresponding author. Institute for Technical Physics I, University of Erlangen-Nuremberg, Germany. Tel.: +49 9131 8528888; fax: +49 9131 8527293.

E-mail address: M.Schardt@web.de (M. Schardt).

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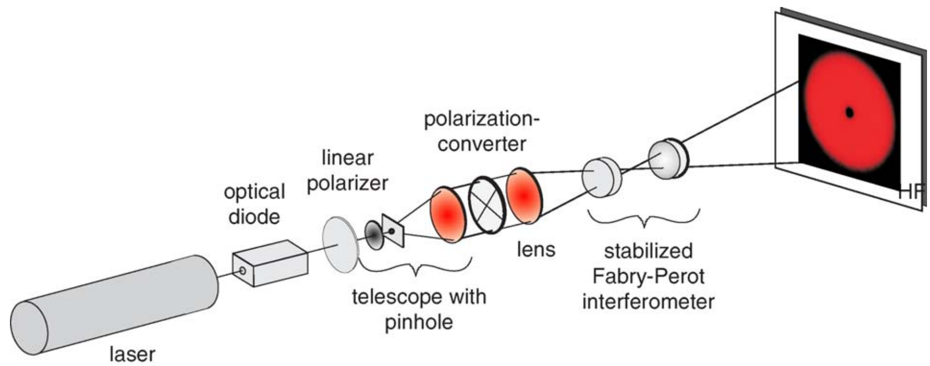

Fig. 1. Preparation of the radially polarized laser beam.

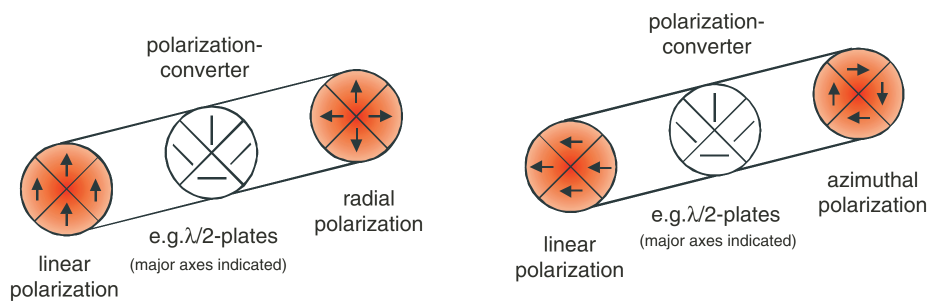

Fig. 2. A polarization converter made of $\lambda/2$-plates: a vertically (horizontally) linear polarized beam is converted into a radially (azimuthally) polarized beam.

Depending on the orientation of linear polarized input (vertically or horizontally) the output beam is polarized either radially or azimuthally. By rotating the linear polarization of the input 90° it is possible to switch between these two polarizations easily. The polarization converter shown in Fig. 2 is limited to a single wavelength only. In our experiments, we use an external cavity diode laser in Littman configuration tuneable from 763 to 789 nm. Polarization conversion is done wavelength independently by a liquid crystal. Our crystal rotates the polarization vector locally thus operating like a $\lambda/2$-"cake" made up of an infinite number of segments [1].

The focussing of a radially (or azimuthally) polarized beam through a microscope objective with high numerical aperture is shown in Fig. 3.

For a radially polarized beam, at the focal tail the transversal components of the electrical field vectors interfere destructively whereas the longitudinal components add up. This leads to a strong TM-polarization on the optical axis. Additional transversal components are located off axis only. Focussing the azimuthally polarized input field results in TE-components only (located off-axis) [2].

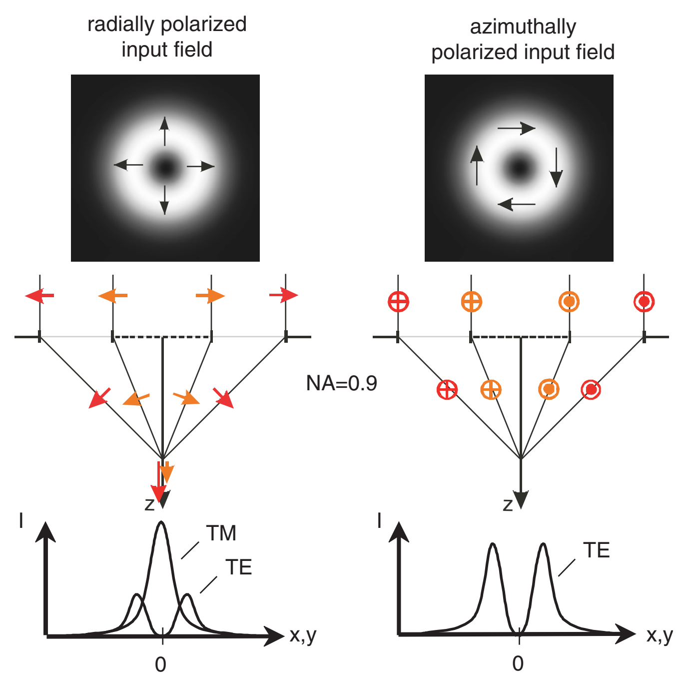

Fig. 3. Focussing a radially polarized beam (left): purely TM-polarized light on the optical axis (TE-contributions off-axis). Focussing an azimuthally polarized beam (right): pure TE-polarization off-axis (no TM-contributions).

2. Quantum wells as test structures

Experimental evidence of the TM-polarization present at the focus of a radially polarized input field was performed by exploiting the polarization-dependent absorption of a quantum well structure (as schematically shown in Fig. 4).

According to the polarization-dependent selection rules (see: Table 1), for TE-polarized excitation light, both light and heavy holes contribute to the absorption spectrum.