Tuneable, radially polarized Laser light for the study of semiconductor nanostructures

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We present an experimental set-up to generate beams of polarization order number +1. These beams were realised using a liquid crystal as a polarization converter. A Quantum well Heterostructure, the absorption of which is polarization dependent is used as a detector at the focus.

Keywords: Liquid crystal LC, Quantum well Heterostructure.

1 Introduction

Laser beams with axially symmetric polarization have many unusual properties making them an excellent instrument for research works. When a radially polarized light is focused with high numerical aperture, a strong longitudinal electric field component in the vicinity of the focus is observed [1]. In contrast, the azimuthally polarized field generates a strong magnetic field on the optical axis, while the electric field is purely transverse and zero at centre.

2 Experimental set-up

The experimental set-up used to generate beams of polarization order number +1 at wavelengths between 767 nm and 787 nm is presented in fig.1.

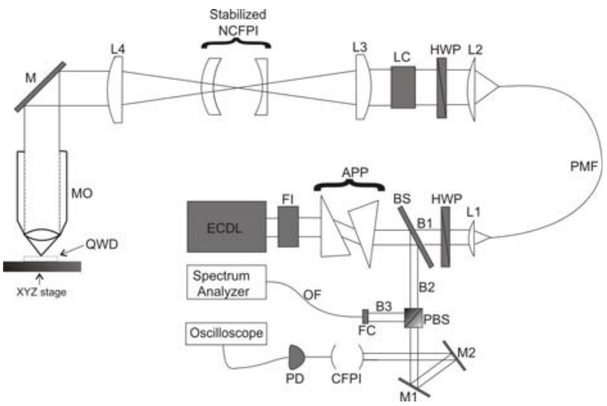

***Figure1**: Experimental set-up: Beam B3 is coupled into optical fiber OF via a fiber connector FC then to the spectrum analyser for wavelength analysis. CFPI is a confocal fabry-perot interferometer and photo detector PD: both used to indicate the stability (details not included) of the laser during the experiment. Microscope objective MO (NA=0.9) focuses the beam onto the Quantum Well Detector QWD. M: four mirrors for polarization insensitive deflection (details not shown).*

The light source is an External Cavity Diode Laser (ECDL) in Littman configuration. The ECDL is protected from back reflections by a Faraday Isolator FI. The ellipticity ratio of the laser beam is ≈ 1:3, and to correct it we use the anamorphic prism pair APP. Beam B1 is focused into a single mode polarization maintaining fiber PMF using an 11 mm focal length aspheric lens L1. We use the fiber for spatial mode filtering. The half-wave plate HWP in front of the fiber is used to rotate the polarization of the beam so that it enters the fiber along the fiber's fast axis. With the APP properly aligned, almost 50% of the laser beam is coupled into the fiber. The coupling efficiency is limited by the residual astigmatism of the beam. The output beam from the fiber is collimated with a 20 mm focal-length Plano convex lens L2. The HWP after this lens rotates the plane of polarization of the beam to the desired orientation before entry into the LC cell. The beam is coupled into a stabilized non-confocal fabry-perot interferometer NCFPI by an achromatic doublet L3 after which it is collimated with a 600 mm focal-length achromatic doublet L4.

The LC cell rotates the polarization of the beam locally. It consists of one unidirectional and one circularly rubbed alignment structure on two opposing glass plates. The space in between the plates is filled with a nematic LC [2]. Transparent electrodes are attached to the plates which supply an alternating voltage aligning the molecules. When the electric field is switched off the LC molecules are left in a metastable state. The molecules that are adjacent to the two plates attain the orientation provided by the plate structure. The orientation of the unidirectional structure defines the LC axis and it is this structure upon which the beam is incident. If a linearly polarized beam with the axis of polarization parallel to the LC axis is incident onto the LC cell, an azimuthally polarized donut mode is generated. If the incident polarization is perpendicular to the LC axis, radially polarized donut mode is generated. We generated these modes and verified their polarization states.

The Quantum well structure used in the experiment is made up of epitaxial layers as shown in fig (2). It was grown using the MBE technique.

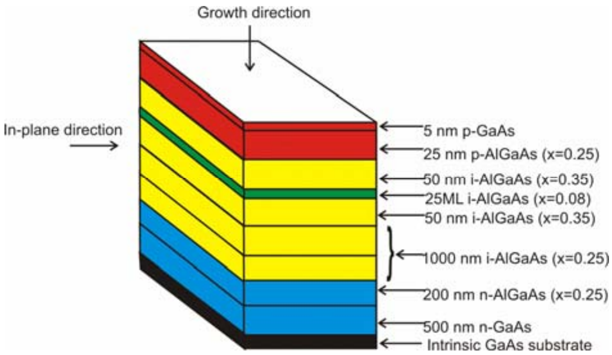

Fig 2: Quantum well heterostructure. x denotes the percentage of Aluminium atoms in a layer of AlGaAs. Percentage of Ga atoms is given by 1-x.

The Quantum well is 25 monolayers ML of intrinsic AlGaAs. The well is surrounded on either side by two barrier layers of intrinsic $Al_{0.35}Ga_{0.65}As$ of the same thickness and composition. The 8% aluminium content in the well layer shifts the excitonic peaks to our wavelength of interest. The heavy and light holes absorption in the quantum well gives rise to transitions as shown below.

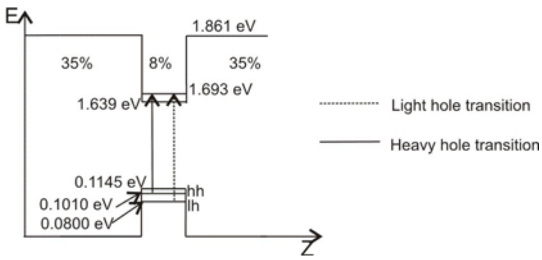

Figure 3: A sketch of the energy band diagram showing the quantum well and the corresponding single particle Eigen values.

When modelling the quantum well structure, the intrinsic electric field is considered together with the excitonic binding energies. A band gap discontinuity of 65% in the conduction band and 35% in the valence band is taken into account.

3 Experiments with the quantum well structure

We used an annular aperture to enhance the longitudinal electric field at the focus of a high NA microscope objective. In air, the focused beam has approximately 70% of longitudinal component but this is reduced to almost 10% after refraction by the material of the quantum well structure. We illuminated the quantum well from the growth direction and measured the spectrum fig (5) by tuning the laser. In this geometry, the focused radially polarized beam has a polarization state as that of the TM polarization in the in-plane geometry.

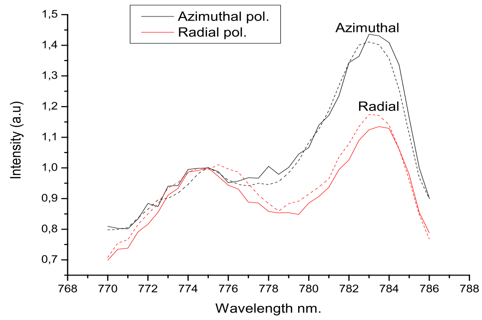

Fig4: Photocurrent spectrum when illuminating the sample from the growth direction. The figure shows the reproducibility of the measurements by comparing two of them done on different days. The dotted curves represent one set of measurements.

The spectra were normalized to 1 at the light hole peaks for the purpose of comparing the absorption of the heavy holes. It is evident that, the amount of transverse component in the focused radially polarized donut mode is much smaller compared to that in azimuthal polarization.

The heavy holes (hh) and light holes (lh) absorption lines were also studied with a different set-up comprising of a white light source and a monochromator. In the set-up, the quantum well was illuminated from the in-plane direction with the beam being either TE or TM polarized. Fig 5(A) and 5(B) is the spectrum obtained. The quadratic quantum stark effect is evident as the negative bias voltage is applied. This indicates that the absorption is occurring in quantum well. Polarization selection rules leads to polarization dependent absorption of the heavy and light holes.

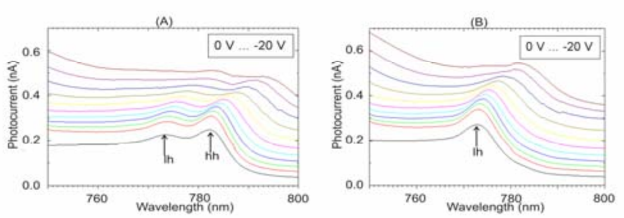

Fig.5: (A) is the photocurrent spectrum with TE polarization and (B) photocurrent spectrum with TM polarization. The bias voltages were varied from 0V to -20V. lh and hh are the light and heavy hole peaks respectively.

4 References

[1] Ralf Dorn, S. Quabis, and G. Leuchs. ''A sharper focus for a radially polarized light beam'', PRL 2003.

[2] M. Stalder, ''Active and Passive optical components using liquid crystals'', Proceedings of SPIE Vol. 2783.