Spatially resolved spectroscopy on trapped excitons

R. Schwartz, Institute of Physics, University of Rostock, Germany (August 2011)

Application Note

The experiment in general

Due to laser induced optical excitation bound electron-hole pairs, so-called excitons, are created in semiconductor bulk material. The density of these excitons is increased by capturing them in a stress induced potential trap. The samples are placed in a cryostat and cooled down to temperatures below 100 mK. The light which is emitted during the decay of the excitons is analysed spatially and spectrally. For this purpose a high resolution triple monochromator is necessary. Usually an iStar ICCD camera from Andor is used as detector at the exit of the Jobin-Yvon monochromator T64000 [1]. Unfortunately, this camera had a failure and was in repair at Andor Technology for some weeks. This gave us the possibility to test another Andor camera, the Newton CCD detector DU940P-BV. Due to the 2-dimensional detector (2048 x 512 pixels) spatial resolved spectroscopy is possible. Unfortunately, there is no gating mode and thus (compared to the iStar camera) the timely development of excitation and decay of the excitons can't be studied.

The experiment in particular

Setup

In the concrete experiment the sample is a cuprous oxide (Cu_2O) cube (Figure 1(b)) with an edge length of about 3 mm. The sample is cooled down to temperatures below 100 mK in a $^3He/^4He$ dilution cryostat. Via optical access windows in the cryostat a focused laser beam (in this case a cw dye laser) creates excitons in the crystal. During their lifetime of some hundred ns the excitons move through the crystal by diffusion and recombine afterwards. During the recombination there is of course light emitted. The light coming from the sample is imaged via a combination of lenses and mirrors on the entrance slit of the monochromator. Figure 1(a) shows the schematic setup of the experiment. On the detection area at the monochromator exit a horizontally spectrally resolved image of the excitonic light appears. In vertical direction the monochromator does not influence the image. It stays spatially resolved in this direction. Thus it is possible to detect the excitonic emission as a function of energy and of vertical position in the sample.

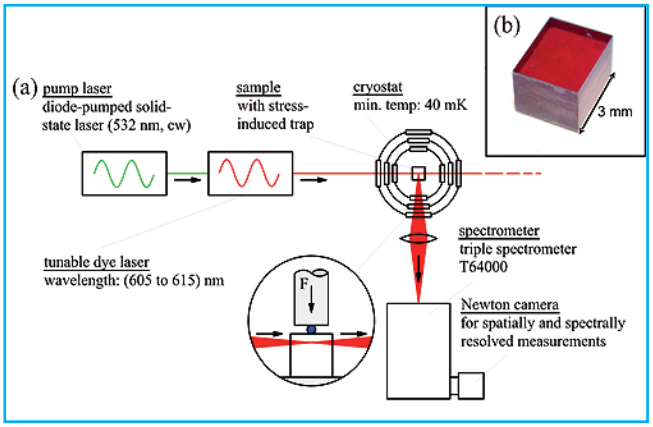

Figure 1: (a) shows a scheme of the experimental setup. In (b) a sample cutted from a natural crystal and polished afterwards is shown.

Trap

For trap creation a sphere or a spherical lens made of glass is pressed on the upper sample surface (see round insert in Figure 1(a)) which causes a special deformation of the lens and the sample (Hertzian contact). Due to the strain in the Cu_2O crystal a potential is created which lowers the energy of the excitons. Thus after their creation underneath the trap they move in the direction of the potential minimum which is situated some µm below the surface which is pressed. In this way very high exciton densities can be achieved which would not be possible by a simple increase of the laser power. Also a laser power increase is always followed by a sample heating which should be avoided in any case.

Measurements

Figure 2 shows a typical spectrum taken with the Newton CCD detector. In horizontal direction there is the energy axis and the vertical direction represents the spatial position, where the lens is pressed from the top. The exciton splits into ortho and para exciton states. Only the ortho excitons can be excited optically. The para excitons are generated from ortho excitons via a conversion process.

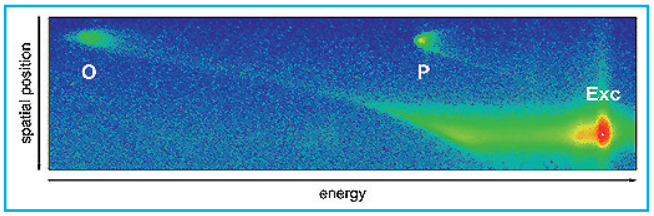

Figure 2: A typical spatially resolved spectrum of excitons in Cu_2O with the initially excited ortho excitons (Exc) and the ortho (O) and para (P) excitons in the potential trap.

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On the right hand side one can see clearly a bright spot (Exc) which represents the luminescence of the ortho excitons excited by the laser. After excitation the ortho exciton energy is decreased because of the trap potential. In the spectrum this is shown by the broad luminescence stripe from the excitation spot to lower energies. For a further decreasing of their energy the excitons have to move spatially in the direction of the potential minimum. There is a thin stripe to top left which represents this moving to lower energies and in spatial direction. Finally the ortho excitons reach the potential minimum and stay there (O). During all the time para excitons are created via an ortho-para-conversion process. They show the same behaviour like the ortho excitons. They also move to lower energies and into the trap minimum. Note that the trap minima are at different energies for ortho and para excitons. Also the spatial position of the minima is a little different.

Conclusion

Although the Newton CCD was just a replacement for the iStar ICCD camera and there is no possibility for time dependent measurements with the CCD, some quite important quantitative measurements in a quasi equilibrium state (excitation with a cw-laser) could be taken. The Newton CCD detector and the high resolution triple monochromator form a powerful tool for spatial resolved spectroscopy.

References

[1] R. Schwartz, 2010, "Orts- und zeitaufgelöste Spektroskopie an dichten Exzitonen", http://www.lot-oriel.com/files/downloads/andor/en/AP_Orts-_und_zeitaufgeloste_Spektroskopie_an_dichten_Exzitonen.pdf

Contact

Rico Schwartz
University of Rostock
Institute of Physics
Workgroup Semiconductor Optics
Universitätsplatz 3
18055 Rostock
Germany

Phone: +49 (381) 498 6783
E-Mail: rico.schwartz2@uni-rostock.de
Web : http://web.physik.uni-rostock.de/halb/