Spectroscopic analysis of erbium-doped silicon and ytterbium-doped indium phosphide

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Summary

In this thesis an optical analysis of the properties of rare-earth doped semiconductors is presented. Research on semiconductors is interesting because many questions about these substances are still unanswered, while modern technology can hardly exist without silicon chips; these can be found in every piece of equipment and even in almost every toy.

On the other hand, optical research is important, *e.g.*, for the improvement of data transport using glass-fibre technology. The rare-earth element erbium can emit infrared light at a wavelength of around 1500 nanometers, which is least absorbed by glass-fibres.

In the first chapter of this thesis, a discussion is given of the effects on the energy levels of the light-emitting atoms due to the symmetry of their environment, when these atoms are imbedded in the crystal of the semiconductors silicon or indium phosphide. Starting from a free erbium ion, first the influence of the spin–orbit coupling is mentioned, and secondly the splitting of the ground level and the first excited level, caused by a crystal field of tetrahedral or cubic symmetry, is calculated.

In chapter 2 the results of an experimental photoluminescence investigation of erbium-doped silicon and silicon oxide are presented. From the resemblance of both spectra it is concluded that the erbium ion is in both cases surrounded by a similar environment, in which oxygen plays an important role. The same can be concluded for erbium in erbium oxide and in gallium arsenide. Both substances show a very strong emitting defect, which seems to be due to erbium atoms surrounded by oxygen, situated near the surface of the sample.

In chapter 3 it is discussed how to identify the five lines belonging to an erbium atom in a crystal field of cubic symmetry, when the luminescence spectrum is known. A transformation of some parameters is given, which is needed to compare the crystal-field splitting of the ground level with that of the excited level. Next the selection rules are discussed, and a numerical method is given to find the most probable identification. Additional contributions to the crystal-field splitting are calculated in second-order perturbation theory. Finally the measured data, given in chapter 2, are interpreted and discussed in more detail.

Numerical computations on the Zeeman splitting of the Er^{3+} ion in a crystalline environment are presented in chapter 4. Different symmetries are investigated, the results are compared with experimental data for about 50 erbium-related electron paramagnetic resonance spectra of cubic, trigonal, tetragonal and orthorhombic crystal sites.

These calculations confirm the empirically found rule about the sum of the *g* values. This subject is fully in development, and in future a connection between the electron paramagnetic resonance spectrum and the optical spectrum of the same defect will be endeavoured.

In the following two chapters another semiconductor is investigated, ytterbium in indium phosphide. A system that, although showing a strong of resemblance with erbium in silicon, is much easier to investigate, simply because it emits a stronger luminescence signal.

In chapter 5 an attempt is made to find the correct sequence of the crystal-field levels in the ground state and the excited spin–orbit multiplet of ytterbium in indium phosphide. Several experiments, providing information on this ordering, will be briefly discussed; these include the luminescence intensity, the temperature and stress dependence, and magnetic resonance results.

In chapter 6 the investigation of ytterbium-doped indium phosphide is continued with measurements of the Zeeman effect of the luminescence lines, in magnetic fields up to 16 tesla. A conclusive debate, also including the results from chapter 5, is held about the sequence of the crystal-field levels in the multiplets of ytterbium in indium phosphide. A new, not yet understood transition of the system to a different state is reported; this transition can only be observed in a high magnetic field under simultaneous strong laser excitation. Further investigations on this phenomenon are recommended.