4 Basic Concepts of Inelastic Light Scattering, Experiments on Quantum Wells

4.1 Macroscopic Approach

4.1.1 General Remarks

Inelastic light scattering – or Raman scattering – is the scattering of light by a medium, where in the scattering process excitations are created (Stokes process) or annihilated (Antistokes process) within the medium. In solids, these excitations can be various types of elementary excitations, like phonons, magnons, or – as considered in this book – electronic excitations. Historically, the scattering by optical phonons, or by internal vibrations of molecules, is called Raman scattering, and the scattering by acoustic phonons Brillouin scattering. For *electronic* Raman scattering, often the term *inelastic light scattering* is used, so in this book. Figure 4.1 shows schematically the Stokes and Antistokes processes, where a photon with energy $\hbar\omega_I$ and momentum $\boldsymbol{k}_I$ is scattered by the creation or annihilation of an elementary excitation with energy $\hbar\omega$ and momentum $\boldsymbol{q}$. The scattered photon has an energy $\hbar\omega_S$ and momentum $\boldsymbol{k}_s$. This means, each scattered photon in the Stokes component is associated with a gain in energy $\hbar\omega$ by the sample. Similarly, the sample loses energy $\hbar\omega$ for each scattered photon in the Antistokes component

$$\hbar\omega_S = \hbar\omega_I \pm \hbar\omega \;, \tag{4.1}$$

where the minus (plus) sign is for the Stokes (Antistokes) process. Conservation of momentum requires

$$\boldsymbol{k}_S = \boldsymbol{k}_I \pm \boldsymbol{q} \;. \tag{4.2}$$

Here, the plus (minus) sign is for the Stokes (Antistokes) process. Schematically, a Raman spectrum of a single excitation with energy $\hbar\omega$ looks like the one displayed in Fig. 4.2. There is a very strong component from elastic scattering at energy $\hbar\omega_I$, e.g., from the surface of the sample. For experiments at low temperatures, as considered in this book for experiments on semiconductor nanostructures, only the Stokes process has a significant probability. Therefore, all experiments presented in this book are exclusively measurements of the Stokes components. Usually, the energy axis of the experimental

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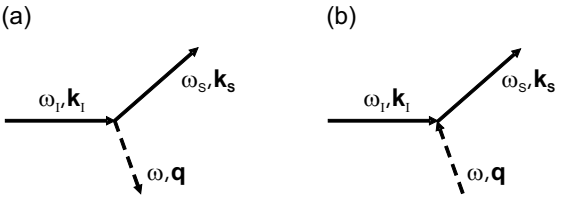

Fig. 4.1. Schematic picture of (**a**) the Stokes, and, (**b**) the Antistokes scattering process

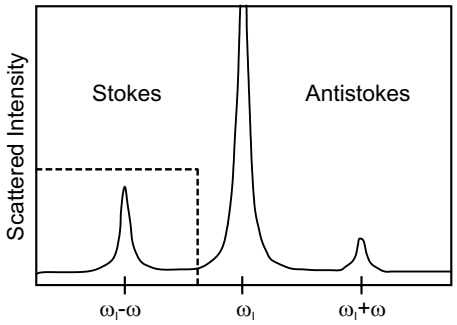

Fig. 4.2. Schematic picture of a Raman spectrum

spectra are shifted so that the origin is at the position of the energy of the incident photons, $\hbar\omega_I$.

In semiconductors, the energies of elementary excitations are always small compared to the energy of the incident laser photons, i.e., $\hbar\omega \ll \hbar\omega_I$. A particular strength of the method therefore is that elementary excitations with energies in the far–infrared spectral range can be measured in the visible range ($\hbar\omega_I$, $\hbar\omega_S$), where powerful lasers and detectors are available. A further strength of the method is the possibility to transfer a finite quasimomentum, or wave vector, $\boldsymbol{q}$, to the excitation during the scattering process. The maximum wave vector can be transferred employing the exact backscattering geometry, i.e., the directions of incoming and scattered light are antiparallel. For this geometry, the maximum value, $q_{\max}$, of the transferred momentum is twice the momentum of the light, under the assumption that the wavelengths of the incoming, λ_I, and the scattered photons, λ_S, are approximately equal:

$$q_{\max} = \frac{4\pi}{\lambda_I} \,. \tag{4.3}$$

For quantum wells, translational invariance is only valid within the plane of the well. In the perpendicular direction, i.e., the growth direction, the translational symmetry is not conserved. Therefore, in experiments on quantum wells, a quasi–continuously tunable momentum transfer is possible in the lateral directions, only. Figure 4.3 shows a schematic picture of the