OPTICAL PROPERTIES OF QUANTUM WELLS

C. Weisbuch
Laboratoire Central de Recherche, Thomson CSF
B.P. 10 - ORSAY, 91401 FRANCE

I - INTRODUCTION

The purpose of the present set of lectures is to introduce students to the field of the optical properties of quantum wells (and superlattices?). As this field has grown out of proportions so as to be covered in three lectures, we have chosen to focus on three areas of the subject which seem to us more appropriate to the aims of the school, namely:

(i) The specific aspects of 2D systems concerning optical properties.

(ii) A description of the techniques of optical spectroscopy so widely used in 3D systems, and their relative qualities when applied to the field of quantum wells.

(iii) The specific design rules and properties of quantum-well lasers (QWLs). As will be seen below, they are quite dominated by "subtle" 2D effects, and QWLs therefore represent a good laboratory to study what are the pros and cons of 2D devices. The discussion of the difficulties encountered with 2D QWLs will then be briefly extended to 1D and 0D devices.

This set of lectures therefore does not discuss many topics concerning the optical properties of quantum wells: calculation of energy levels, optical properties of type II quantum wells and superlattices, strained-layer superlattices, nips, Ge$_x$Si$_{1-x}$ superlattices, II-VI quantum wells and superlattices (both wide or narrow gap), light-scattering phenomena,
electric$^9$ and magnetic field perturbations$^{10}$ of optical spectra, hot-electron phenomena as studied by optical techniques$^{11}$ etc... Excellent coverage of these fields can be found in other lectures in this school or in recent reviews. Time-resolved spectroscopy will only be briefly discussed in direct relation with other topics presented in these lectures.

As is clear from the preceding discussion of what is not included here, these lectures are only concerned with the optical properties of type I quantum wells, even so restricting us to interband transitions.

II - THE OPTICAL TRANSITION PROBABILITY

All interband optical phenomena near a band extremum can be expressed in terms of the dielectric function:

$$\varepsilon(\omega) = \varepsilon_1(\omega) + i\varepsilon_2(\omega) = \varepsilon_0 + \frac{4\pi\beta\omega_0^2}{\omega^2 - \omega_0^2 + i\omega\Gamma}$$

(1)

where $\varepsilon_1$ and $\varepsilon_2$ are the real and imaginary part of the dielectric function respectively, $\varepsilon_0$ is the background dielectric functions (involving all crystal quantum states but the quasi-resonant state), $\beta$ is the polarizability of that resonant state with energy $\omega_0$ and damping constant $\Gamma$. Such a description of optical properties through the dielectric function has been very widely used to describe modulation spectroscopy of 3D-systems$^{12}$. A large amount of information is contained in $\beta$ such as the description of quantum states in uncorrelated one-electron states or in correlated exciton states, the dimensionality of the Density of States (DOS) and type of the transition (number of negative effective masses in the joint DOS) etc... To our knowledge, no detailed quantitative analysis of QW phenomena has been performed in the dielectric function framework, but we will use it below for the description of some experiments. The reader is deferred to the very good reviews of the field$^{12}$ for the description of the properties of $\varepsilon(\omega)$, its quantum-mechanical calculation and its relation to various optical properties. It suffices to recall here that $\varepsilon_1$ and $\varepsilon_2$ are related through the Kramers-Kronig relations, and that $\varepsilon_2(\omega)$ is very directly proportional to the absorption coefficient $\alpha(\omega)$ as calculated from time-dependent perturbation theory (Fermi's golden rule). We can therefore write:

$$\alpha(\omega) \propto |<f|\hat{\varepsilon} \cdot \hat{p}|i>|^2 \varepsilon(\omega)$$

(2)