A theory of coherent propagation of light wave in semiconductor

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In this paper, we suggest a theory to describe the phenomena which arise from the interaction between semiconductor and coherent light. Our work is presented in three parts. In the first part, we neglect the interaction between the electrons and investigate the problem in the framework of single-electron band theory. The intense light field induces not only interband transitions, but also intraband transitions of electrons and holes respectively in the conduction and valence bands. Hence our system is different from the ordinary inhomogeneously broadened two-level system. For our treatment we have adopted the "space translation approximation", i.e. the approximate steady states of the carriers moving within their respective bands under the action of the light wave are taken as the base for treating the interband transition. This is effected by a transformation, which renders the system formally analogous to an inhomogeneously broadened two level system, but a particular type of multiphoton process will occur here.

In the second part, we take into account the interaction between electrons. From the point of view of the resonant coherent interaction with light, the interaction between electrons can be partitioned into a part that does not change the total momentum of the relevant electron-hole pair and another part that does change the total momentum. When we are considering the coherent propagation, it is reasonable to take account of the former while neglecting the latter. Because the intense light pulse can generate a high density of excitons, we must treat the electrons and holes which make up the excitons, as "Fermions". This differs from usual treatments representing excitons at low density as "Bosons". We have introduced coherent states of the exciton to describe the process, and obtained a set of non-linear equation which can naturally account for the saturation of light absorption of exciton and the shift of exciton line in intense light field.

In the third part, we shall analyze the propagation of coherent light pulse in the system, and derive the Maxwell-Bloch equation describing this process. The equation provides a theoretical basis for treating coherent propagation problems. After making some approximation, we can represent this equation in a standard form which can be solved by the "inverse scattering method".

In this paper, for the sake of clarity and simplicity, we have adopted a simple two band model. It is fairly obvious that the main conclusions will not be qualitatively different for more realistic band structures.

半导体中光的相干传播理论

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本文的目的是发展一个理论来描述半导体与相干光相互作用所引起的许多现象。我们将分作三个部分来叙述我们的工作。在第一部分中，我们不考虑电子-电子间的相互作用，在单电子能带理论基础上来讨论这些问题。强的光场不仅会引起电子在能带之间的跃迁，而且还要引起电子在导带内，空穴在价带内的运动，因此，它和通常的非均匀展宽的二能级系统是不同的。我们用了空间平移近似，即用电子和空穴在光场作用下带内运动的近似稳态波函数来作为带间跃迁的基，形式上还可以归结为一个非均匀展宽二能级系统，但这时会有一种特有的高阶多光子过程。

在第二部分中，我们考虑了电子-电子间的相互作用。从与光的共振相干作用来看，电子间的相互作用可分作两类：一类是不改变所产生的电子空穴对的总动量的，一类是要改变这个电子空穴对的总动量的。换句话说，前者是电子和“自己的”空穴的相互作用，即通常所说形成激子态的相互作用；后者是电子、空穴之间的碰撞，它要破坏过程的相干性。在我们考虑相干传播现象时，当然，应当考虑前者，而可以略去后者。强的相干光可以产生相当高浓度的“激子”，因此，构成激子的粒子（电子和空穴）的“费米性”必须加以考虑。这就和通常在弱激发时把激子当作波色子是不同的。我们引入了激子的相干态来描述这种过程，它可以对光吸收的饱和，激子线在强光下的移动等提供自然的解释。

在第三部分中，我们分析了相干光脉冲在这个系统中的传播。得到了描述这种过程的麦克斯韦-布洛赫方程。它可以作为分析相干传播过程的基础。在一定的近似下，它可以变成一种用反散射方法来解的标准形式。

为了使我们的讨论比较简明，我们只对一个简单的抛物型的二带模型来进行分析。显然，所得的结论不会因为二带模型与实际能带的差别而有性质上的不同。