ECE 462 Presentation

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Unexpected transition from single to double quantum well potential induced by intense laser fields in a semiconductor quantum well

Background Information

- ✓ Understanding how external electromagnetic fields affect “low-dimensional systems” is important for nanoelectronics
- ✓ Recent developments in high-power tunable lasers (such as FELs) has fueled this area of research
- ✓ This paper wants to better estimate the effects of high-frequency intense laser fields (ILFs) on quantum wells and their corresponding “bound states"

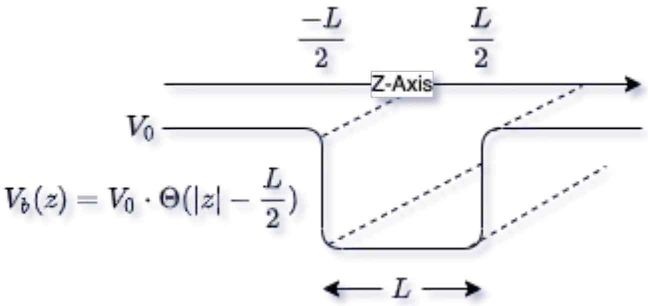
What’s Already Known

- ✓ The behavior of potentials are understood for a laser-dressing parameter (denoted by α_0) whose value is $\alpha \leq \frac{L}{2}$
  - i. However, our current laser technology yields α_0 values of tens of nanometers
- ✓ Therefore, true behavior of infinite wells for these cases is not understood
  - i. This paper investigates how linearly polarized, nonresonant ILF’s affect these quantum wells’ potential, and provides α_0 a closed-form expression for the potential for **all** values of

The Quantum Well

✓ This paper defines the quantum well I've tried to illustrate below:

   i. Very similar to the infinite well from class, except finite



The Quantum Well

- ✓ Movement in this quantum well can be defined as:

$$\Psi(\rho, z) = e^{ik_\perp \cdot \rho} * \chi(z)$$

- ✓ Where in ρ is movement in-plane (unrestricted by the well), and along the z-axis is with the well's potential
- ✓ Assuming a uniform effective mass throughout the semiconductor, the energy is thus:

$$\epsilon = \frac{k_\perp^2}{2m^*} + E_n$$

The Schrödinger Equation

✓ The exact solution of the time-independent Schrödinger equation (1) yields (2)

$$E_n \chi_n(z) = -\frac{\hbar^2}{2m^*} + V_b(z)\chi_n(z)$$

(1)

$$\chi_n(z) = \begin{cases} (-1)^n B e^{\kappa_b (z+\ell)}, & z \leq -\ell \\ A f(\kappa z), & |z| < \ell \\ B e^{-\kappa_b (z-\ell)}, & z \geq +\ell, \end{cases}$$

(2)

Adding the Perturbation

- ✓ Now, when this quantum well is perturbed by a monochromatic, non-resonant EM field - the effects on the bound states can be analyzed by including the external field in the kinetic portion of the Hamiltonian

$$\Psi(z,t)\left(\frac{(p+eA)^2}{2m^*}+V_b(z)\right)=i\hbar\frac{\partial\Psi(z,t)}{\partial t}$$

- ✓ Implementing the periodic potential of the laser, the previously mentioned analytical solution for $V(z)$ can be found, but is only valid for $\alpha_0 \leq \ell$

Accounting for **All** Values of ***a***

✓ To begin solving for all positive values of ***a***, the substitution $u = \omega t$ is made on the expectation of the potential, V, leading to:

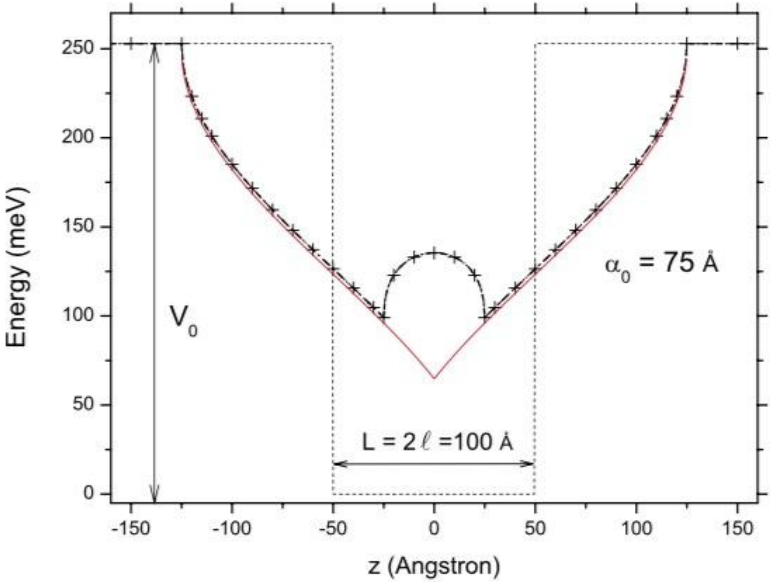
$$< V > (z; \alpha_0) = \frac{V_0}{2\pi} \int_0^{2\pi} \Theta(|z + \alpha_0 sin(u)| - \ell) du$$

✓ This is then simplified to remove the integral, resulting in:

$$< V > (z; \alpha_0) = \frac{V_0}{\pi} [\Theta(\alpha_0 - z - \ell) cos^{-1}(\frac{\ell + z}{\alpha_0}) +$$
$$\Theta(\alpha_0 + z - \ell) cos^{-1}(\frac{\ell - z}{\alpha_0})]$$

Difference in Solutions

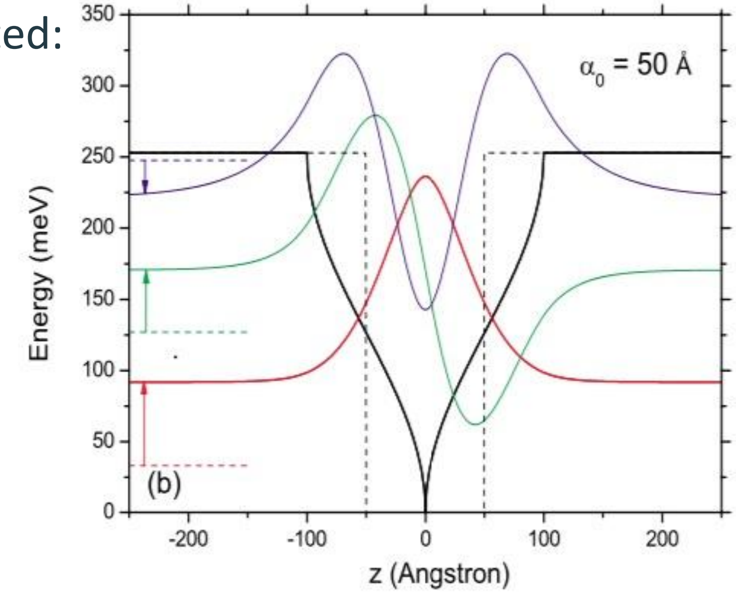
✓ This analytical solution shows quite a large difference when applied to a real well:



Practical Application With $\alpha_0 \leq \ell$

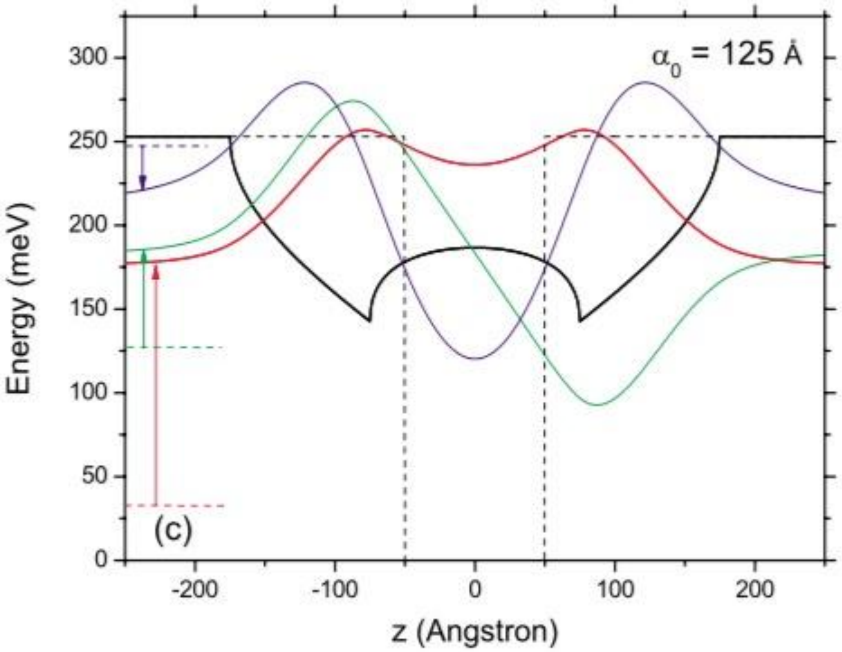
✓ When applying this to the numerical problem of GaAs and AlGaAs as materials, the solution is as expected:

- Energies below $\frac{V_0}{2}$ feel an effective well width smaller than L, and are thus blue-shifted
- While energies above this threshold experience a wider well, red-shifting them.



Practical Application With $\alpha_0 > \ell$

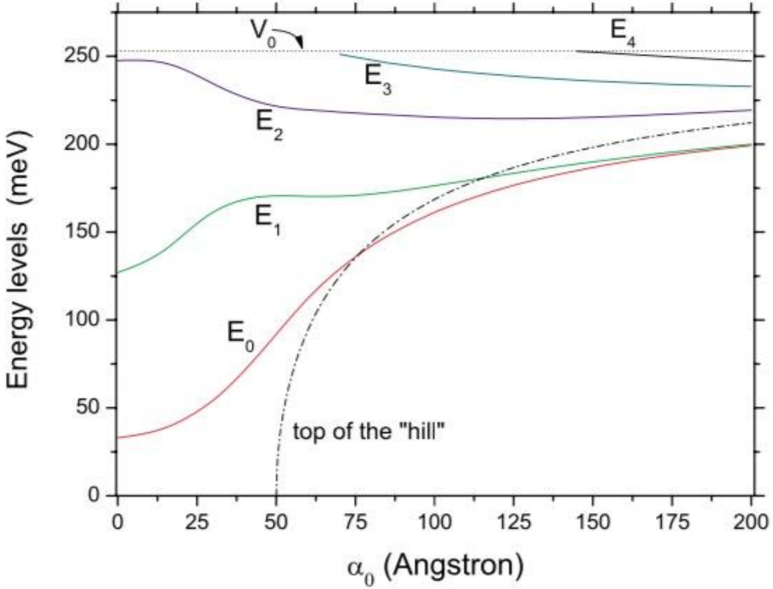
✓ The effect of the laser becomes really drastic, and the 'double-well' emerges



Practical Application With $\alpha_0 > \ell$

✓ Now, the effects on the eigenenergies as a function of the laser-dressing parameter can be plotted

- What becomes plainly evident is the coalescence of the bound states as the parameter increases,
- Inevitably, extra bound states begin appearing



Future Applications

- ✓ This coalescence feature can be used as a basis for "population control" in optical pumping laser-schemes
- ✓ The emergence of the double-well opens the possibility of creating controllable resonant states
  - Distinct from typical resonance of a double-well semiconductor structure because of the lack of need to finely tune the structure
- ✓ Should a weak electrostatic field be added in the z-axis, the well's symmetry would break, theoretically permitting the possibility of a double-well resonant tunnel diode with controllable characteristics.

Questions?