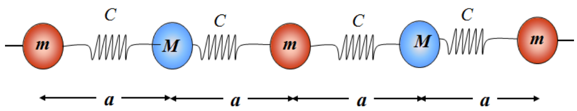
OPTICAL EXCITATION

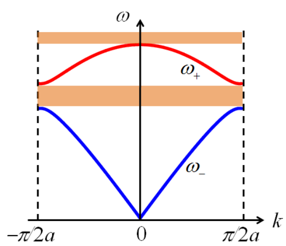
Overview: Lecture 5

- Diatomic lattice:



- Equations of motions → Solutions → Dispersion relations:

$$\omega^2 = \frac{C(m+M)}{mM}\left[1 \pm \sqrt{1 - \frac{4mM\sin^2 ka}{(m+M)^2}}\right]$$

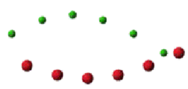


- Two branches:
  - Acoustic

$$\frac{u_{2n+1}}{u_{2n}} \approx 1$$

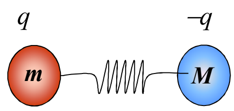
- Optical:

$$\frac{u_{2n+1}}{u_{2n}} = -\frac{m}{M}$$



2

Overview: This Lecture

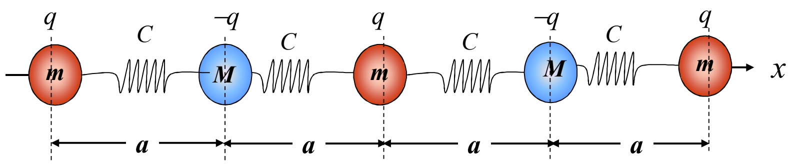
- Optical Excitation: 

- Equations of motions → Solutions → Resonance
- Reststrahlen effect and band

3

Optical Excitation

- Consider polar crystals.



- The crystal will have an optical mode of vibration with frequency ω_+.
- At $k = 0$, $\omega_+(0) = \sqrt{2C(1/m + 1/M)}$
- Consider x-directed propagating transverse electric field,

$$E = E_0 e^{-i\omega_0 t}$$

- The electric field will force the atoms to oscillate at frequency ω_0.

4

Equations of Motion

- For atoms $2n$ and $2n+1$, with masses m and M, respectively,

$$F_{2n} = m\frac{\partial^2 u_{2n}}{\partial t^2} = C_t\left(u_{2n+1} + u_{2n-1} - 2u_{2n}\right) + qE_0 e^{-i\omega_0 t}$$

$$F_{2n+1} = M\frac{\partial^2 u_{2n+1}}{\partial t^2} = C_t\left(u_{2n+2} + u_{2n} - 2u_{2n+1}\right) - qE_0 e^{-i\omega_0 t}$$

- **Solutions:** $u_{2n} = Ae^{i(2kna - \omega_0 t)}$

$$u_{2n+1} = Be^{i[k(2n+1)a - \omega_0 t]}$$

$$u_{2n+2} = Ae^{i[k(2n+2)a - \omega_0 t]} = u_{2n}e^{i2ka}$$

$$u_{2n-1} = Be^{i[k(2n-1)a - \omega_0 t]} = u_{2n+1}e^{-i2ka}$$

Solutions

- Replacing the solutions in the equations of motion

$$\left(2C_t - m\omega_0^2\right)u_{2n} - C_t\left(1 + e^{-i2ka}\right)u_{2n+1} = qE_0 e^{-i\omega_0 t}$$

$$-C_t\left(1 + e^{i2ka}\right)u_{2n} + \left(2C_t - M\omega_0^2\right)u_{2n+1} = -qE_0 e^{-i\omega_0 t}$$

- Assume $k = 0$, so that

$$e^{\pm i2ka} = 1$$

- Simplification:

$$\left(2C_t - m\omega_0^2\right)u_{2n} - 2C_t u_{2n+1} = qE_0 e^{-i\omega_0 t}$$

$$-2C_t u_{2n} + \left(2C_t - M\omega_0^2\right)u_{2n+1} = -qE_0 e^{-i\omega_0 t}$$

Solutions

$$u_{2n} = \frac{-qE_0 / m}{\omega_0^2 - \omega_+^2(0)} e^{-i\omega_0 t}$$

$$u_{2n+1} = \frac{qE_0 / M}{\omega_0^2 - \omega_+^2(0)} e^{-i\omega_0 t}$$

- $\omega_+(0)$ is the transverse optical mode frequency for $k = 0$

$$\omega_+(0) = \sqrt{2C_t\left(\frac{1}{m} + \frac{1}{M}\right)}$$

Resonance

$$\omega_0 = \omega_+(0)$$

- Mathematically, the amplitude of oscillation becomes infinite at resonance.
- **Reradiation:** Accelerated charges radiate electromagnetic energy → strong reradiation of energy at the excitation frequency.

Reflections

- Electromagnetic signals with frequency near resonance exhibit reflection from the crystal.
- This behavior can be explained from the change of the index of refraction

  → Dielectric constant ∝ Dipole moment

  ∝ Oscillation amplitude

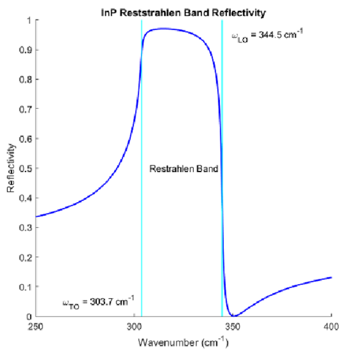
  → Refractive index is determined by the dielectric constant and will experience a sharp change near resonance.
- The real permittivity of the material is negative in this range with a large imaginary permittivity analogous to metals → high reflectivity.

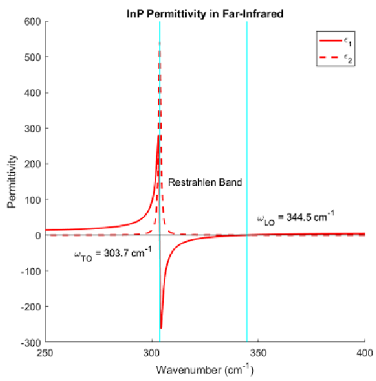
Reststrahlen Effect

- The radiation by the ionic substance is called **Reststrahlen** effect

  → Observed only in ionized or polar crystals.

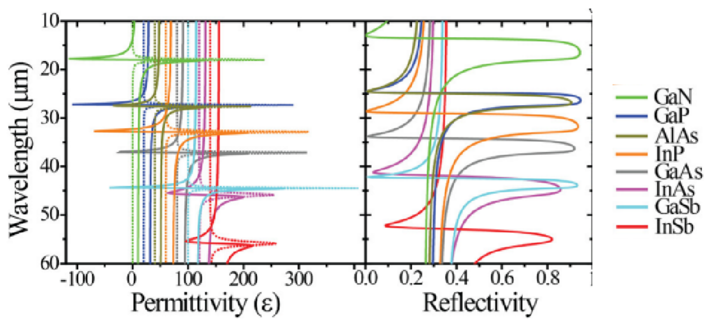
  → Measure of the ionicity: Stronger in NaCl than in GaAs.





Reststrahlen Band

- Between 20-100 μm for different material.
- SiC, diamond, III-nitrides: 10-20 μm.
- III-V materials: 20-40 μm.
- Continuous spectrum infrared radiation can be converted into monochromatic by multiple reflections → Forbidden band.



11

Class Test – 1

20 November 2018

Syllabus: Topics covered till date

12