Proposal for the Study for Semiconductor Planar Phonon Cavity

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Resonant cavities have been studied since 1877, when Lord Rayleigh published his *Theory of Sound*. They have achieved great achievements in optics fields. Fabray and Perot cavity is a notable example. With distributed Bragg reflectors (DBR) combined, Fabray and Perot optical cabity is widely used as a light filter, such as single-wavelength photo-detector, or a container for photons with a certain wavelength, such as used in LASERs. Figure 1 shows a layer structure for a single-wavelength photodetector[1]. As designed, only the light with wavelength of 1542nm can pass through the cavity and DBRs, reaching the p-i-n regoin underneath. The reflection spectra is shown in Figure 2.

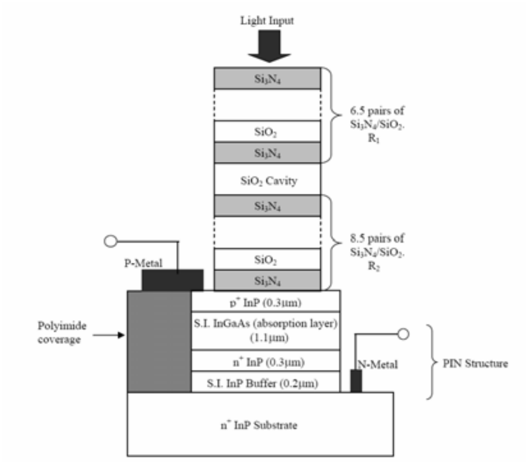

Figure 1 Layer structure for single-wavelength photo-detector. DBRs and Fabray-Perot cavity is used.

The DBR structure is composed with periodic units to enhance the selectivity of wavelength. In each unit, there are two layers A and B with different refractive indeces. The thickness of each unit is equal to half of the wavelength λ_p to be passed through. So the thickness of layer A and B may be $\lambda_p/4$ separately. The thickness of the cavity is also the half of the λ_p. The more periods used in DBR, the better the light is filted. But considering the dissipation of light in the DBRs, too many periods is not desired. So selecting the material for layers with large difference in the refractive indices is also helpful to enhance the filting effect.

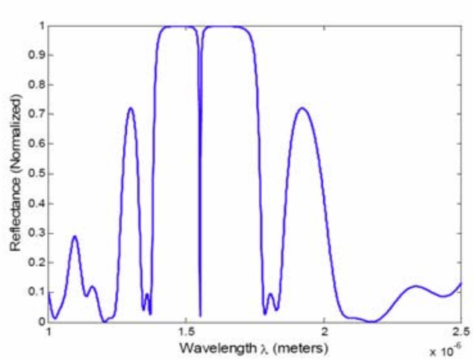

Figure 2 Simulated reflection spectra of the filter on the photo-detector

Phonons are similar with photons in some sence. Both of them are waves with a certain wavelength and have reflection or transmission spectra between different materials. Since phonon is actually the vibration of lattice atoms, instead of being related with refractive index in optical materials, the transmission of phonons depends more on the atom mass of the layer where they are propagating.

Device researchers are interested in acoustic phonons because they are related with the energy disipassion and lattice heating during the device operation. And by designing proper phonon cavities, it is possible to create directional energy flow of lattice excitations in active electronic devices.

Trigo *et al.*[2,3] have performed the first studies of the scattering of standing-wave photons from standing-wave phonons by placing an acoustic phonon cavity inside an optical cavity, which is used to enhance the interaction between photons and phonons. The structure is shown in Figure 3. Their research shows the possibility for the generation of coherent phonons. The thinkness of the phonon cavity is $\lambda_{ac}/2$, where λ_{ac} is the wavelength of the acoustical phonon at the center of the phonon minigap.

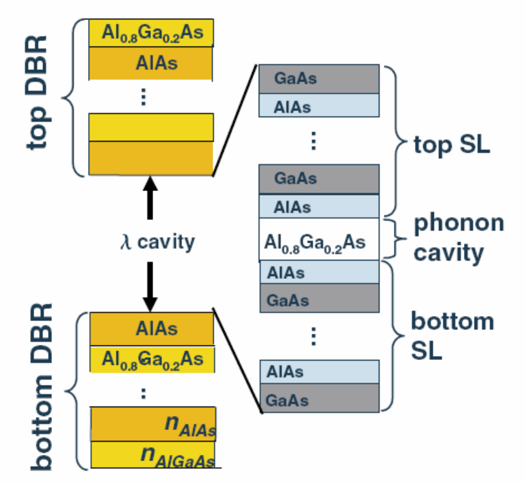

Figure 3 Structure of the phonon cavity embedded within an optical cavity.

Raman spectrum can be used to analyze the phonon mode staying in the cavity. But applying Transfer Matrix Method, the phonon reflectivity and Raman spectrum can both be calculated, which is shown in Figure 4.

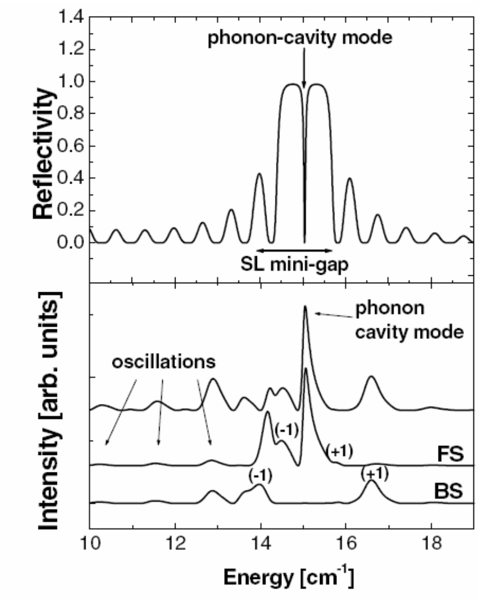

Figure 4 Calculated phonon reflectivity and Raman spectrum for the phonon cavity embedded within a photon cavity.

Studies on acoustic phonon in nitrides are of special interests because nitride devices are normally used for high-power applications. Device heating is an important issue.

We would like to design a phonon cavity by AlN/GaN with a similar structure as Trigo did. First of all, we need to develop a general expression for the phonon transimission via any periodic structures. The expression for the lattice displacement is[4]

$$U = \sum_{n=1}^{3} A^n e^n \exp[i(k_n \bullet x - \omega t)], \qquad (1)$$

where n stands for the index of the possible phonon modes in the layers [n=1, shear horizontal; n=2, shear vertical; n=3, longitudinal], e is the unit polarization vector, A^n is the nth component of the amplitude vector, ω is the angular frequency, and k is the wave vector. This expression satisfies the equation of motion which is

$$\rho \frac{\partial^2 U_j}{\partial t^2} = c_{jklm} \frac{\partial^2 U_l}{\partial x_k \partial x_m}, \qquad (2)$$

where c_{jklm} is the elastic constant tensor and ρ is the mass density. The solution of the displacement should also satisfy the boundary conditions, i.e., continuity of displacement and normal stress.

With these boundary conditions, the relation between displacements in different layers can be expressed in an inhomogeneous linear system like

$$\begin{pmatrix} T \\ J \end{pmatrix} = \begin{pmatrix} \Pi_{11} & \Pi_{12} \\ \Pi_{21} & \Pi_{22} \end{pmatrix} \begin{pmatrix} I \\ R \end{pmatrix}, \qquad (3)$$

where T (R) is the transmitted (reflected) amplitude for the three modes and I (J) is the input amplitude from – (+) ∞. What we need to do here is to find out the expressions for all the units in the transfer matrix $\begin{pmatrix} \Pi_{11} & \Pi_{12} \\ \Pi_{21} & \Pi_{22} \end{pmatrix}$ for

Al(Ga)N/GaN systems.

[1] S. Vicknesh, Y. Cao, A. Ramam, Proceeding of Optics West, 2006.

[2] M. Trigo, A. Bruchhausen, A. Fainstein, B. Jusserand, and V. Thierry-Mieg, *Phys. Rev. Lett.* **89**, 227402 (2002).

[3] A. Fainstein, B. Jusserand, and V. Thierry-Mieg, *Phys. Rev. Lett.* **75**, 3764 (1995).

[4] A. Catellani and L. Sorba, *Phys. Rev. B* **38**, 7717 (1988)