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Effect of the Built-In Strain on the In-Plane Optical Anisotropy of *m*-Plane GaN/AlGaN Quantum Wells

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We study theoretically the influence of the anisotropic biaxial strain originating from the lattice mismatch between the m-plane GaN/AlGaN quantum wells structure and the substrate on the optical anisotropy of such systems. It is demonstrated that the oscillator strengths for optical transitions with polarization of light parallel and perpendicular to the crystal axis c strongly depend on strain to such an extent that, by increasing the concentration of Al in the substrate from $x = 0$ to $x = 0.5$ one can change the polarization of the emitted light with respect to the c-axis by 90 degrees.

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1. Introduction

Group III–nitrides heterostructures grown along non-polar directions of the wurtzite structure (corresponding to a-plane $\{11\bar{2}0\}$ or m-plane $\{1\bar{1}00\}$) are attractive for applications and basic research due to the lack of built-in electric field which is present in the structures grown along the polar, c-plane $\{0001\}$ orientation. Although crystals and heterostructures with polar surface orientation are usually of higher quality than in the case of non-polar orientation and are characterized by almost isotropic optical response, strong quantum confinement Stark effect seriously reduces the radiation efficiency of such systems. This effect is avoided in the non-polar structures allowing for substantial enhancement of optical efficiency e.g. by properly engineering the wave function overlap in quantum wells. However in this case, the rotational symmetry along the direction of growth is broken resulting in strong in-plane optical anisotropy associated with polarization dependent selection rules for fundamental optical transitions [1]. The built-in strain caused by the lattice mismatch between the quantum well and the substrate may further enhance the anisotropy of the emitted light polarization. This effect may be exploited as a tool for studying the light–matter coupling in semiconductor lasers and microcavities.

In the present study we investigate theoretically the influence of the built-in strain on the electronic structure and optical transition oscillator strengths for the m-plane GaN/AlGaN quantum wells grown on AlGaN substrates with different aluminum contents.

2. Model

The oscillator strength for interband transitions in GaN/AlGaN quantum wells is obtained by solving the eigenvalue problem in $k \cdot p$ envelope function approximation. We consider full Rashba–Sheka–Pikus Hamiltonian for the valence band and anisotropic, parabolic Hamiltonian for the conduction band [2].

The anisotropic built-in strain elements entering both Hamiltonians are calculated by applying the linear theory of elasticity and assuming that the structure is pseudomorphic [3].

We find eigenstates of electrons in the conduction and valence bands by solving a system of differential equations obtained from bulk $k \cdot p$ Hamiltonians by replacing the p_y component of the momentum by $-\mathrm{i}\hbar\frac{\partial}{\partial y}$, where y-axis is parallel to the growth direction. The parameters for $Al_xGa_{1-x}N$ are estimated using the linear interpolation between binaries except for the energy gap and the spontaneous polarization for which bowing is taken into account as in Ref. [4].

3. Results and discussion

The calculations were performed for a 5 nm GaN/$Al_{0.2}Ga_{0.8}N$ quantum well grown on the $Al_xGa_{1-x}N$ substrate with x less than 0.5. In Fig. 1 we show principal strains, ϵ_{xx} and ϵ_{zz} in-plane of the quantum well and ϵ_{yy} — perpendicular to the quantum well. The anisotropy of the in-plane strain measured by the difference between the ϵ_{zz} (with z-axis parallel to the c-axis of the wurtzite crystal) and ϵ_{xx} increases with the content x of aluminum in the substrate.

The influence of strain on optical transition energies and corresponding oscillator strengths for light polariza-

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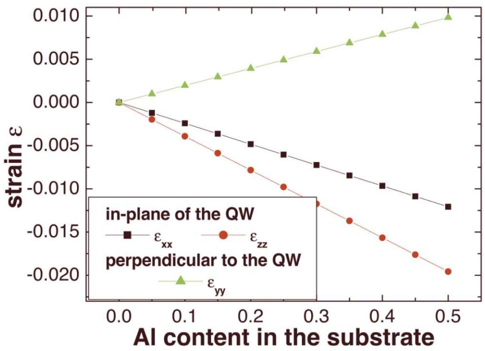

Fig. 1. Principal strains in 5 nm wide GaN/ $Al_{0.2}Ga_{0.8}N$ quantum well as a function of aluminum content in the substrate.

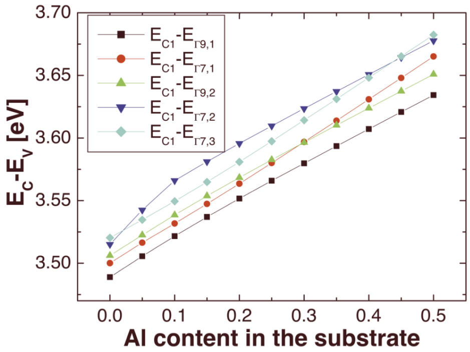

Fig. 2. Interband optical transition energies from the five topmost valence subbands to the lowest energy conduction subband in 5 nm wide GaN/$Al_{0.2}Ga_{0.8}N$ quantum well as a function of aluminum content in the substrate.

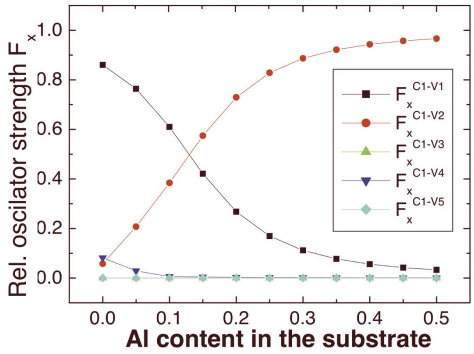

Fig. 3. Oscillator strength of optical transitions with polarization along the x-axis in 5 nm wide GaN/ $Al_{0.2}Ga_{0.8}N$ quantum well as a function of aluminum content in the substrate.

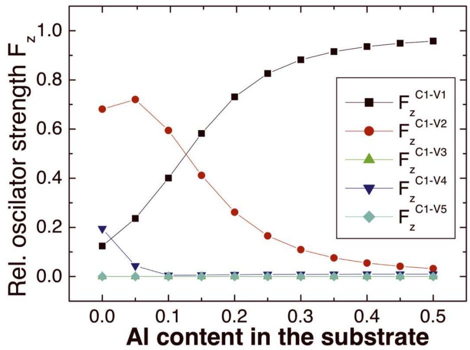

Fig. 4. Oscillator strength of optical transitions with polarization along the z-axis in 5 nm wide GaN/ $Al_{0.2}Ga_{0.8}N$ quantum well as a function of aluminum content in the substrate.

tion along x- and z-axis is presented in Figs. 2, 3 and 4, respectively. In the case of unstrained quantum wells, i.e. for $x = 0$, the lowest energy transition (c1–v1) corresponds to the valence band level with the Γ_9 symmetry and the next transition (c1–v2) is associated with Γ_7 symmetry. Therefore, the oscillator strength of the c1–v1 transition is large for the in-plane polarization perpendicular to the c-axis and much smaller for the polarization parallel to the c-axis. On the other hand, the next transition c1–v2 is dominant for the polarization parallel to the c-axis and almost negligible for the polarization perpendicular to the c-axis.

With increasing Al content x in the substrate all transition energies increase and so does the energy separation between the c1–v1 and the c1–v2 transitions. At the same time the oscillator strength for the c1–v1 transition decreases for the in-plane polarization perpendicular to the c-axis and increases for the polarization parallel to the c-axis. The opposite occurs for the c1–v2 transition. As the result, by increasing the concentration of Al in the substrate from $x = 0$ to $x = 0.5$ one can change the polarization of the emitted light with respect to the c-axis by 90 degrees.

4. Conclusions

In conclusion we find that the optical anisotropy of the m-plane GaN/AlGaN quantum wells is strongly influenced by the anisotropic biaxial strain which originates from the lattice mismatch between the structure and the substrate. This effect should be taken into account when designing m-plane structure based devices in which polarization of light plays an important role such as microcavities and polariton lasers.

Acknowledgments

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