

carrier with a different frequency by adjusting the DC bias, this is particularly useful in wireless systems that use frequency diversity to reduce cross talk among adjacent cells. The output of each laser is split into M carriers hence a single self-pulsating DFB is shared among M cells using the same carrier frequency. Each carrier is modulated then directed to a different multiplexer. Each multiplexer combines carriers with different wavelengths and transmits them through a single fiber, therefore N wavelengths share the same fiber. Another advantage of WDM is it limits the speed of the electronics needed at the base station to the bit rate of the individual cell. If the cells are scattered and cross talk is of no importance, WDM allows each cell to use the full RF bandwidth. The figure demonstrates how a cluster of seven cells are able to share the fiber from the control station then use a demux to supply a different millimeter-wave carrier to each cell. The output of each multiplexer may be configured according to need.

The basic principles of the network is demonstrated using two 60 GHz self-pulsating DFB lasers emitting at 1548.4 nm, and 1549.9 nm. First the output of the lasers are split, then a multiplexer is used to combine carriers of different wavelengths into the same fiber, enabling the support of four cells over two fibers. The WDM/self-pulsation signal is transmitted over 14 km of fiber, at the receiver end a filter is used to extract the designated self-pulsation. The optical spectra of the transmitted WDM/self-pulsation

and the filtered self-pulsation at the receiver are shown in figure 2. For data transmission the lasers are sub-harmonically injection locked then modulated with a 155 Mb/s PSK data at a 1 GHz offset. The RF spectrum of a modulated 60 GHz self-pulsation is in figure 3 along with the phase noise of the carrier. The spectrum is measured by optically downconverting the received signal by 17 GHz. The figure compares the actual measured phase noise with the estimated phase noise when the penalty due to optical downconversion is taken into consideration.

A network architecture based on wave division multiplexing of self-pulsating DFB lasers for 60 GHz wireless systems is proposed and demonstrated. The network offers sharing of resources and combines the advantages of remote generation of millimeter-wave carrier and WDM.

References

1. G. Smith, D. Novak, and Z. Ahmed, "Overcoming Chromatic-Dispersion Effects in Fiber-Wireless Systems incorporating External Modulators," *IEEE Trans. Microwave Theory Tech.*, Vol. 45, No. 8, August 1997, p.1410-1415.
2. M. AL-mumin, X. Wang, W. Mao, S. Paper, and G. Li, "Optical generation and Sideband Injection Locking of Tunable 11-120GHz Microwave/Millimeter Signals," *Elect. Lett.* vol. 36, NO.18, August 2000, pp 1548-1549.
3. M. AL-mumin, X. Wang, W. Mao, G. Li, "Optical Generation and Self Sub-harmonic In-

jection Locking of Tunable 10-100 GHz Microwave/Millimeter Signals", in *Conference on Lasers and Electro-Optics, OSA Technical Digest*, May 2000, pp. 96-97.

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Spontaneous polarization effects on the optical properties of piezo-strained InGa_N quantum wells

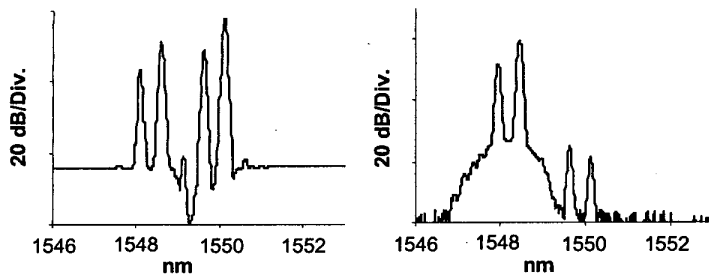
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Rapid development in the epitaxial growth, doping control, and device processing on group III nitride has brought in a plethora of research activity. Although much attention has been emphasized on the device application, ambiguities still exist on the emission mechanism of InGa_N quantum wells (QWs). Due to the inhomogeneity issues in the material growth, it has been suggested the efficient radiative recombination of InGa_N QW is due to the localized carriers at the band-tail states. Others suggest the emission is from the highly localized, quantum dot-like states in the phase-separated In-rich regions in the well. Controversy also remains on the gain and lasing mechanism of the nitride lasers. While the more traditional argument favors the mechanism of electron-hole plasma recombination originating from free carriers, some suggest the carrier localization in the plane of the QW layers can enhance the quantum efficiency.¹

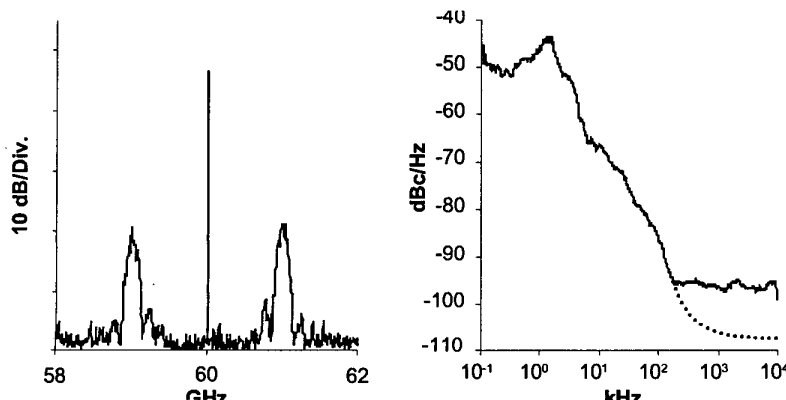
In resolving the fundamental emission mechanism of III-V nitride, it is recently noticed that the discontinuity of macroscopic polarization can induce 2D-electron or hole gas at the interface.² The polarization-induced charge is related to the piezoelectric- and the spontaneous-polarization of the wurtzite structure. In GaN/AlGa_N QWs, the difference in the spontaneous polarization can result in a strong field in the well even with the absence of the piezoelectric field.³ Combined with the information shown above, it is desirable to design an optical study immune from the localization effects such that contribution from the spontaneous polarization effects can be clearly resolved.

In this work, high-excitation spectroscopy is used to study the optical properties of strained InGa_N QWs. By engineering the spontaneous polarization induced charge to have opposite sign in the symmetric and asymmetric QWs, large spectral blue shifting (~ 140 meV) and linewidth narrowing (~ 10 meV) are observed. These effects are attributed to the charge screening of the polarization field and enhanced radiative recombination in the electron-hole plasma regime.

The 3.0 nm In_{0.15}Ga_{0.85}N QW samples used in this study were grown on a ~1.5 μm GaN buffer layer on the (0001) sapphire substrate in an AIX 200/4 low-pressure MOCVD system.⁴ In order to investigate the polarization effects, symmetric GaN/InGa_N/GaN and asymmetric GaN/InGa_N/AlGa_N QW structures were used with a top



CTHL56 Fig. 2. Left—Multiplexing of the two self-pulsations at the transmitter (The multiplexer consists of a grating and a circulator). Right—The filtered output at the receiver.

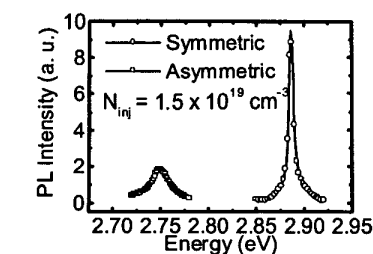


CTHL56 Fig. 3. (a) 155 Mb/s PSK signal transmitted on a 60 GHz carrier, (b) Phase noise of the 60 GHz carrier, solid—actual measured phase noise, dash—phase noise when the penalty of optical downconversion is considered.

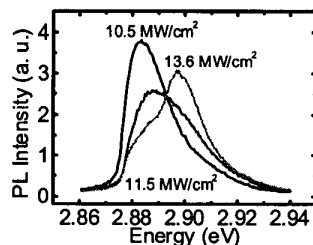
barrier of 50 nm thickness. In doing so, the piezoelectric field in the compressive-strained InGa_{0.15}N QW is to point toward the substrate direction. Moreover, the design of the symmetric InGa_{0.15}N QW is to have the spontaneous polarization induced charge opposite to that of the asymmetric QW case. As a result, the piezo- and the spontaneous-polarization effects add up in the latter case whereas they tend to compensate each other in the former case. To ensure a complete filling of the localized states, the optical study was made with a KrF excimer laser excitation (Tui-Laser ExciStar 2000) with a pulse width of 10 ns, repetition rate of 10 Hz, and maximum pulse energy of 14 mJ. The experiments were taken in a surface emission configuration to minimize the reabsorption effect on the photo-luminescence (PL) spectra. The data were recorded by a spectrometer equipped with a CCD array detector.

Shown in Fig. 1 (a) are the normalized room-temperature time-integrated room-temperature PL spectra of the 3.0 nm InGa_{0.15}N QWs, and (b) the corresponding emission linewidth dependence on the instant excitation power density. We first note a large ~ 140 meV spectral shifting between the 3.0 nm InGa_{0.15}N QWs capped with different top barriers. Moreover, with the increase of the excitation density, the high-energy part of the spectra is found to take an exponential dependence on the energy. This feature signifies the hot-carrier effect.⁵ We also note a pronounced linewidth narrowing effect with the pump density. Using this pump technique and material choice, linewidth as narrow as 10 meV can be achieved in the symmetric InGa_{0.15}N QW at room temperature.

Shown in Fig. 2 are the self-consistent analysis on the emission spectra of the 3.0 nm InGa_{0.15}N QWs taken into account the many-body, charge screening, piezoelectric- and spontaneous-polarization effects.⁶ A carrier injection of $N_{inj} = 1.5 \times 10^{19} \text{ cm}^{-3}$ is assumed in the analysis. It is found the compensation mechanism of the spontaneous- and piezoelectric-polarization in the symmetric InGa_{0.15}N QW can greatly reduce the internal field in the well and lead to a substantial spectral blue shifting and enhancement in the emission intensity. In the regime where the linewidth narrowing takes place, the calculation indicates the transition is mainly due to the free carrier recombination in the QW subbands. Further shown in Fig. 3 are the high-excitation PL spectra of the 3.0 nm symmetric GaN/InGa_{0.15}N/GaN QW at a pump intensity greater than 10 MW/cm². The salient features in the transition from the linewidth broadened (~ 20 meV) to the multi-peak emission spectra clearly reveal the subband-filling effects. These observations suggest that in the high-excitation regime, the mechanism of electron-hole plasma recombination is responsible for the InGa_{0.15}N QW emission spectra.



CTH57 Fig. 2. Calculated optical emission spectra of the symmetric and asymmetric 3.0 nm InGa_{0.15}N QWs.

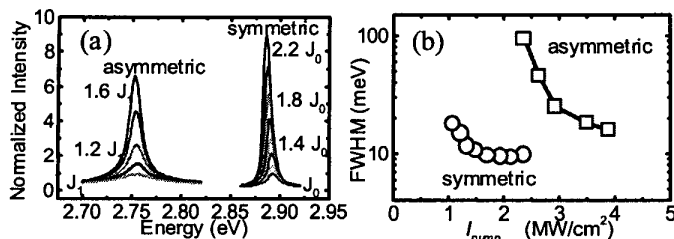


CTH57 Fig. 3. High-excitation PL spectra of symmetric 3.0 nm GaN/In_{0.15}Ga_{0.85}N/GaN QW.

anism of electron-hole plasma recombination is responsible for the InGa_{0.15}N QW emission spectra.

In summary, we show the engineering of spontaneous polarization in the symmetric InGa_{0.15}N QWs can enhance the optical transition energies and emission intensity. In the high-excitation regime, the mechanism of electron-hole plasma recombination is found to dominate in the emission spectra. This research was sponsored by the NSC Grant No. 89-2215-E-002-041 and 047.

1. Y.-H. Cho, T.J. Schmidt, S. Bidnyk, G.H. Gainer, J.J. Song, S. Keller, U.K. Mishra, and S.P. DenBarrs, "Linear and nonlinear optical properties of InGa_{0.15}N/GaN heterostructures," *Phys. Rev. B* 61, 7571–7588 (2000).
2. V. Fiorentini, F. Bernardini, F.D. Sala, A.D. Carlo, and P. Lugli, "Effects of macroscopic polarization in III-V nitride multiple quantum wells," *Phys. Rev. B* 60, 8849–8858 (1999).
3. S.-H. Park and S.-L. Chuang, "Spontaneous polarization effects in wurtzite GaN/AlGa_{0.15}N quantum wells and comparison with experiment," *Appl. Phys. Lett.* 76, 1981–1983 (2000).
4. C.-C. Chuo, C.-M. Lee, T.-E. Nee, and J.-I.



CTH57 Fig. 1. (a) normalized PL spectra of the symmetric and asymmetric 3.0 nm InGa_{0.15}N QWs. $J_0 = 1 \text{ MW/cm}^2$, and $J_1 = 2.4 \text{ MW/cm}^2$, (b) linewidth dependence on the excitation power density.

Chyi, "Effects of thermal annealing on the luminescence and structural properties of high indium-content InGa_{0.15}N/GaN quantum wells," *Appl. Phys. Lett.* 76, 3902–3904 (2000).

5. F. Binet, J.Y. Duboz, J. Off, and F. Scholz, "High-excitation photoluminescence in GaN: hot-carrier effects and the Mott transition," *Phys. Rev. B* 60, 4715–4722 (1999).
6. L.-H. Peng, C.-W. Chuang, and L.-H. Lou, "Piezoelectric effects in the optical properties of strained InGa_{0.15}N quantum wells," *Appl. Phys. Lett.* 74, 795–797 (1999).

CTH58

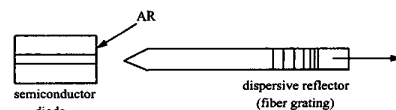
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Stability properties of dispersive extended-cavity semiconductor lasers

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Since semiconductor diode dispersive extended-cavity lasers are currently of interest for a variety of applications,^{1,2} understanding their stability properties is important to ensure stable CW laser operation. These lasers consist of a semiconductor diode coupled to some sort of external dispersive reflector (e.g. a fiber grating) that forms one mirror of the laser cavity; see Fig.1 for a schematic. Quite unexpectedly, experiments have shown that for chirped fiber grating lasers (FGL), the orientation of the grating drastically alters the stability of CW operation:³ when the grating was placed such that the index modulation period decreased with distance from the coupled diode facet, stable single mode operation occurred, but the opposite grating orientation resulted in significant mode-hopping. This result is counter-intuitive, since the grating reflectivity spectra are identical in both cases; the only difference is in the sign of the curvature of the reflection spectrum phases, and this has been shown to play only a small role in large-scale current modulation dynamics.⁴

In this presentation, we not only explain these curious experimental results, but we also find a simple numerical prescription with which the stability of any such system can be assessed, provided the reflection spectrum of the external reflector is known. We perform a linear stability analysis wherein we seek the response of the deviation of the electric field from steady state, $\psi(t)$, given a small perturbation from the steady state. Using an accurate but simple model for the semiconductor diode developed earlier,⁵ we find an expression for the Laplace transform of $\psi(t)$, denoted by $\hat{\psi}(s)$, that is given explicitly in terms of the reflection spectrum of the dispersive reflector as a function complex frequency; this spectrum is easily calculated for a fiber grating, for example. We then determine laser stability simply by locating the singularities of $\hat{\psi}(s)$ over



CTH58 Fig.1. Schematic drawing of a semiconductor diode dispersive extended-cavity laser.