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 are 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

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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.

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Spontaneous polarization effects on the optical properties of piezoestrained InGaN quantum wells

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Rapid development in the epitaxial growth, doping control, and device processing on group III nitrides 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 InGaN quantum wells (QWs). Due to the inhomogeneity issues in the material growth, it has been suggested the efficient radiative recombination of InGaN QW is due to the localized carriers at the band-tail states. Others suggest the emission 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.4

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.7 The polarization-induced charge is related to the piezoelectric- and the spontaneous-polarization of the wurtzite structure. In GaN/AlGaN QWs, the difference in the spontaneous polarization can result in a strong field in the well even with the absence of the piezoelectric field.8 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 InGaN 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 In0.15Ga0.85N 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/InGaN/GaN and asymmetric GaN/InGaN/AlGaN QW structures were used with a top

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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.

20 dB/Div. 1546 1548 nm
20 dB/Div. 1550 1552 nm

10 dB/Div. 58 60 62 kHz
-40 dB/Hz 101 102 103 104 kHz
barrier of 50 nm thickness. In doing so, the piezoelectric field in the compressive-strained InGaN QW is to point toward the substrate direction. Moreover, the design of the symmetric InGaN 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 formal case. To ensure a complete filling of the localized states, the optical study was made with a KrF excimer laser excitation (Tsunoda et al., 2001) 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 In_{0.15}Ga_{0.85}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 InGaN 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. 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 InGaN QW at room temperature.

Shown in Fig. 2 are the self-consistent analysis on the emission spectra of the 3.0 nm InGaN QWs taken into account the many-body, charge screening, piezoelectric- and spontaneous-polarization effects. A carrier injection of $N_\text{inj} = 1.5 \times 10^{19} \text{cm}^{-3}$ is assumed in the analysis. The compensation mechanism of the spontaneous- and piezoelectric-polarization in the symmetric InGaN 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/InGaN/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 InGaN QW emission spectra. In summary, we show the engineering of spontaneous polarization in the symmetric InGaN 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.


Since semiconductor diode dispersive extended-cavity lasers are currently of interest for a variety of applications, 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: 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.

In this presentation, we not only explain these curious experimental results, but 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, we find an expression for the Laplace transform of $\Psi(t)$, denoted by $\Psi(s)$, 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 $\Psi(s)$ over...