Telecommunication-Wavelength Lasing in Er-doped GaN Multiple Quantum Wells at Room Temperature

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Abstract: We report the realization of room-temperature, stimulated-emission in Er-doped-GaN multiple-quantum-wells at the 1.5-µm. Structures were grown by MOCVD and lasing was confirmed by threshold-behaviors of emission-intensity as functions of pump-fluence, spectral-linewidth-narrowing, excitation-length.
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1. Introduction

The possibility of coherent light generation in semiconductors has attracted a great deal of attention for semiconductor-based, especially Si-based, optoelectronics applications due to the potential for forming inexpensive, monolithic integrated optical components [1, 2]. Due to the relatively small and indirect band gap, Si is a poor light emitter. Light emission in Si has thus focused on the use of Si nanocrystals [3], Ge dots in Si [4], and InGaAs/GaAs nanolasers grown on Si [5-7]. However, these prototype devices essentially lack the advantages associated with the Si system by requiring an external pump laser source or function only at low temperatures. While room-temperature luminescence has been realized [3, 8], optical gain have been under discussion and fundamental problems remain.

The incorporation of rare earth elements, such as Er or Eu, into semiconductor hosts gives rise to sharp, atomic-like and temperature independent emission lines under either optical or electrical excitation [1, 2, 9-11]. Er ions with intra-4*f* shell transitions from its first excited state ($^4I_{13/2}$) to the ground state ($^4I_{15/2}$) produce 1.5 µm emission, which falls within the minimum loss window of optical fibers for optical communications. Lasers operating around 1.5 µm are highly important for use in defense, industrial processing, medicine, spectroscopy, imaging and various other applications. Even after tremendous effort, 1.5 µm emission from Er doped narrow-bandgap semiconductors, including Si and GaAs, has a low efficiency at room-temperature due to the strong thermal quenching effect [12].

2. Samples and experimental results

The Er-doped GaN multiple quantum wells samples were prepared by metal organic chemical vapor deposition (MOCVD) on a c-plane sapphire substrates and had excellent material qualities [13, 14]. The X-ray diffraction and photoluminescence (PL) measurements indicated that GaN:Er epilayers have high crystallinity, without second phase formation, and exhibit a strong room-temperature emission at 1.5 µm with a low degree of thermal quenching [15]. In this work, a set of 200-period Er-doped GaN/AlN multiple quantum wells (MQWs:Er) produced a significant improvement of the quantum efficiency of the 1.5 µm emission via carrier quantum confinement and strain engineering. A detail description of the growth process and epilayer structure has been reported previously [13-17].

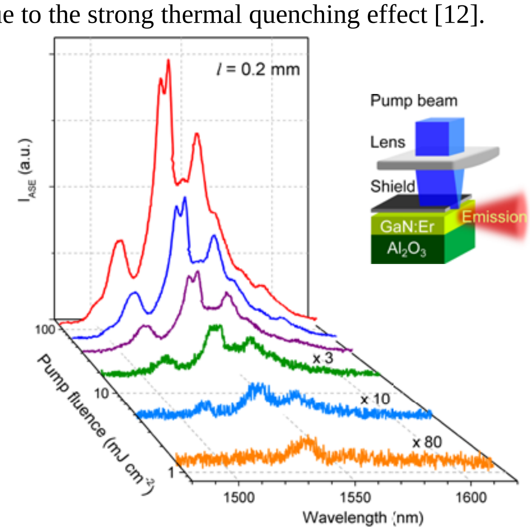

Figure 1: Power dependent PL spectra obtained with an 8 µm wide and 0.2 mm long pump excitation. At low excitation pump fluence, the emission is broad with the FWHM of 30 meV. When the pump fluence is high enough for the optical layer to have net gain, the spontaneously emitted photons are exponentially amplified by stimulated emission and the spectral peaks become narrower.

3. Discussion

Room-temperature PL spectra from the MQWs:Er samples were measured under the band-to-band excitation using an Ar laser at 351 nm (Figure 1). When the emission was collected from the surface, the spectra show a broad spectral feature around 1.5 µm, which is the spontaneous emission of light from Er optical centers in MQWs. As previously reported, the full-width at half-maximum (FWHM) of the 1.5 μm emission at room-temperature is 60 nm for MQWs:Er samples [13, 14]. The broadening of the emission in MQWs is due to the fluctuation of the GaN quantum well width and the local atomic structures around Er optical centers. This is especially a factor for Er optical centers located close to the quantum well/barrier interfaces.

Figure 1 shows edge-emission spectra, under the band-to-band excitation, from the MQWs:Er samples at different pump fluence, P. The spectra provide evidence of room-temperature lasing from the Er optical centers in the MQW structure. In order to achieve lasing, both edges of the MQWs:Er sample were polished to obtain a cavity. In these measurements we employed a long excitation area with 8.0 ± 0.3 μm width and 200 ± 0.5 μm length. The photon fluence of the Ar laser was varied from 0.05 to 120 mJ cm^{-2}. At low excitation pump fluence (P < 15 mJ cm^{-2}), the emission at 1.5 μm shows a broad spectrum with the FWHM of 60 nm (~30 meV) which corresponds to the spontaneous emission [13]. When the pump fluence was higher (P > 15 mJ cm^{-2}) the MQWs:Er samples showed a net optical gain. The spontaneously emitted photons were exponentially amplified by stimulated emission as they traveled through the waveguide in the active medium, leading to a superlinear increase in emission. Since the gain was a maximum near the peak of the spontaneous emission spectrum, the spectrum exhibited "gain narrowing" [14]. Consequently, an intense beam with spectral narrowing was emitted from the edge of the sample. The PL spectra at high excitation pump fluence indicate a number of strong and narrow PL lines. When P > 15 mJ cm^{-2}, the FWHM of the spectrum dropped to 1.60 ± 0.25 meV, which is the signature of optical amplification of the spontaneous emission from Er optical centers in the MQW structure.

In this paper, we focus on excitation of the strongest PL line at 805.30 meV. Figure 2 shows the light-in-light-out data, which is the dependence of the amplified spontaneous emission on the pump fluence. Below the threshold, the PL dependence is linear and a superlinear increase in emission intensity with pump fluence was observed [18]. Above the threshold, most of the excitation centers were stimulated to emit light into waveguide modes, leading to a large fraction of the light emission from the edge [14]. We have employed the well-known variable excitation length method to determine the gain coefficient from the evolution of the peak-emission intensity. The inset in Figure 2 shows the PL intensity for different excitation lengths under an optical excitation of 109 mJcm^{-2}. When the excitation length was increased, the emission spectral peaks became narrower and the output intensity grew exponentially [14].

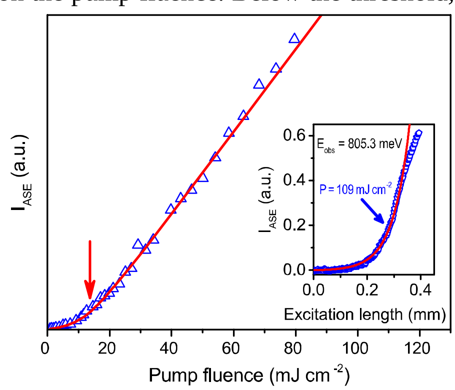

Figure 2: The edge-emission intensity showing linear behavior below threshold (arrow) and superlinear increase at higher fluence. (inset) Optical gain determination via variable stripe length method for the PL line at 805.3 meV.

In conclusion, our investigations provide conclusive evidence of light amplification and stimulated emission in MQWs:Er samples grown by MOCVD. Lasing action at room-temperature was observed at 1.5 μm along with stimulated threshold, spectral linewidth narrowing, and strong modal gain.

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5. References

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