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Stress Distribution in Multiple Quantum Well Stacks and its Effect on Optical Emission Energy Using Cathodoluminescence in a STEM

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We present a broad-range experimental study of vertical emission energy shifts in GaN/AlGaN multiple quantum wells (QW), with respect to structure. Multiple techniques were utilized, such a cathodoluminescence (CL) in a scanning transmission electron microscope (STEM) at low accelerating energies (60-80-kV), electron energy loss spectroscopy (EELS), probe corrected z-contrast for structure imaging, and high resolution TEM (HRTEM) coupled with geometric phase analysis (GPA) for strain mapping.

The study comprises room and liquid nitrogen temperatures studies of the relationship between stress and optical emission energy, at different thicknesses, simultaneously measured with EELS.

Because of the mismatch between the GaN buffer and the AlGaN QW barriers, the QW stack emission is red-shifted at the interface with the buffer (i.e. QWs at the interface are exposed to a lower compressive strain from the AlGaN barriers than the ideal pseudomorphic one), then their emission shifts vertically to the blue and tends to the fully strained emission energy. This is illustrated in Fig.1, which features CL measurement in a STEM at 80kV, (a) is the bright field survey image of the 67 GaN/AlGaN QWs c-grown on a GaN buffer layer, with the line-scan trace (along the c-axis) drawn on it, (b) is the line-scan crude spectrum image at a temperature of 90K (scan step: 1.5 nm) dispersed in wavelength, in which we clearly see the continuous strain-induced blue-shift with decreasing distance to the free surface, and (c) a high resolution z-contrast image of the QW structure. We can see a comparison between room temperature (300K) and liquid nitrogen temperature (90K) spectra obtained in similar experimental conditions (probe size, position on sample, mirror alignment, spectrometer dispersion, acquisition time), in (d): signal at 90k is obviously higher (the room temperature spectrum is multiplied by 5 for better graphical presentation), and narrower. Furthermore, background noise is higher in the room temperature spectrum in comparison with the emission peaks. Fig1. (e-f) quantify the amplitude of the spectral energy shifts observed in (b): the continuous blue shifts observed in (b) have an overall amplitude of about 4 meV for both bulk GaN and the GaN quantum wells. The light was dispersed with a 1200line/mm grating, which, as shown, is sufficient for detecting sub-meV spectral features.

We demonstrate that STEM-CL can bring insight into nanoscale sub-meV emission fluctuations and explain optical phenomena observed by non-local techniques such as photoluminescence. Further analysis involving finite elements strain simulations and k.p calculations of optical emission are undergoing.

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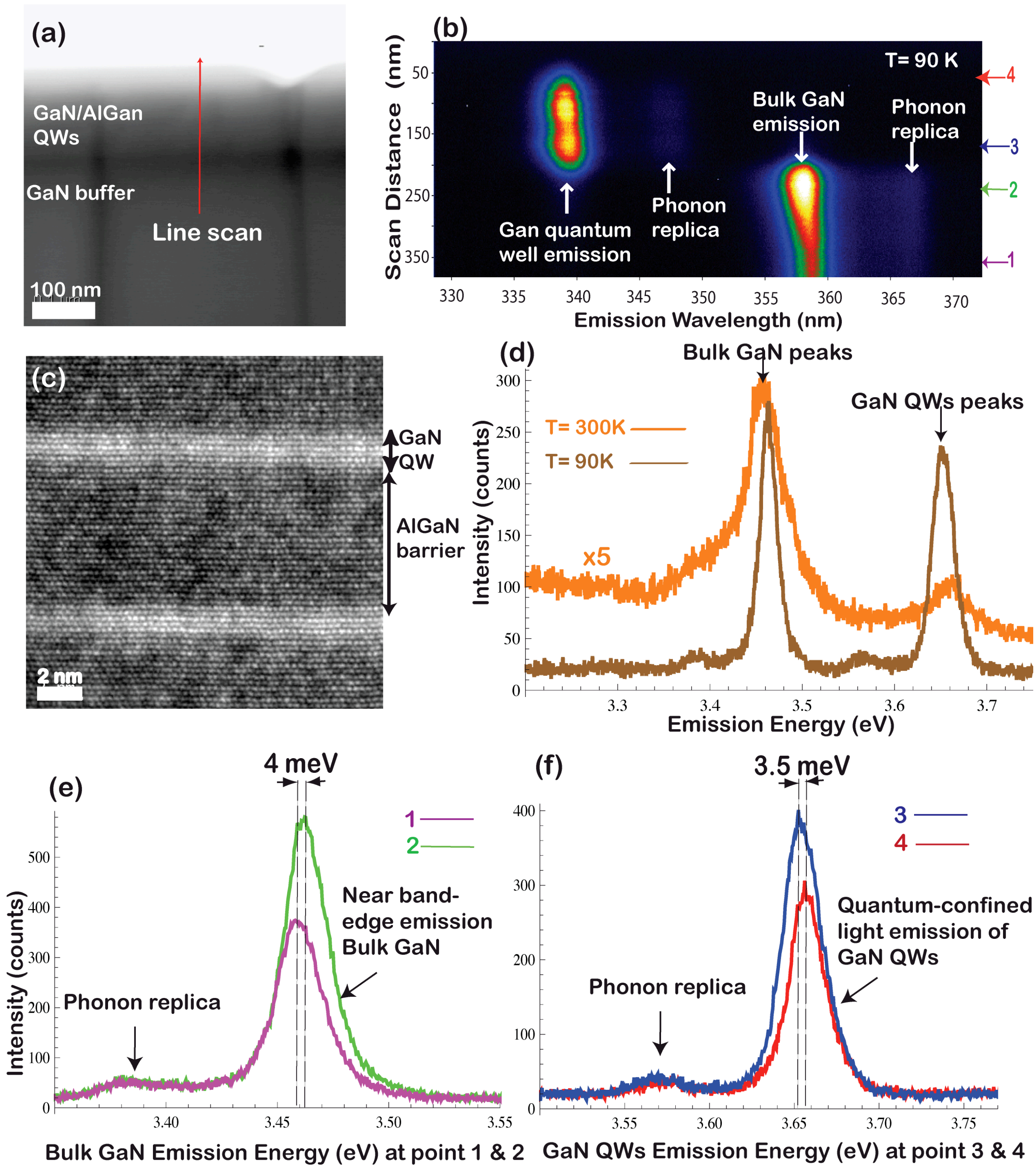

Fig.1: (a) Bright Field Survey image of 67 GaN/AlGaN QWs on a GaN buffer layer, (b) STEM-CL raw spectral image, (c) High resolution z-contrast image of 2 QWs, (d) comparison between 90K and room-temperature spectra, (e-f) energy range of spectral shifts highlighted by spectrum pairs in bulk GaN (e) and the QWs (f).