Light Hole and Heavy Hole Revealed by Quantum Oscillations in GaN/AlN 2D Hole Gas

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Gallium Nitride (GaN) has been a leading contender in commercial high-frequency and high-power applications due to its internal polarization field and a wide bandgap of 3.4 eV [1]. When interfaced with AlN, the different polarization and bandgap of wurtzite GaN and AlN generates, without requiring any chemical doping, a two-dimensional carrier gas with sheet density (~5e13 cm^{-2}) much higher than that in other material systems like modulation-doped GaAs and silicon inversion channels. [1, 2].

While n-channel devices based on GaN's two-dimensional electron gas (2DEG) progress towards higher performance, its p-type counterpart has been lagging due to the low mobility of the two-dimensional hole gas (2DHG), hindering the development of GaN-based CMOS [1]. More fundamentally, low hole mobilities precludes a direct measurement of hole effective masses by quantum oscillations or cyclotron resonance. In the absence of reliable and uniform experimental data, researchers have had to rely on theoretical calculations [3, 4].

Using a GaN-on-AlN heterostructure grown by plasma-enhanced molecular beam epitaxy (PA-MBE), we report Shubnikov-de Haas (SdH) oscillations in the interfacial 2DHG – the first observation, to our knowledge, in p-type GaN. Magnetoresistance measurements were performed at the National High Magnetic Field Laboratory Pulsed Field Facility, showing single-frequency SdH oscillations with an onset at around B=25 T (Fig. 1). At temperature below 4 K, another set of oscillations with higher frequency and smaller amplitude is discernable at the highest fields, suggesting another subspecies of holes with higher sheet density and lower scattering lifetime (lower quantum mobility). Fourier analysis of the magnetoresistance reveals two oscillation frequencies – attributed to light holes (LH) and heavy holes (HH) – with sheet densities of ~8e12 cm^{-2} and ~4e13 cm^{-2}, respectively. The densities of light and heavy holes are separately confirmed by fits of low-field $R_{xx}(B)$ and $R_{xy}(B)$ to a classical two-carrier Drude model and consistent with multi-band k.p calculations (Fig. 2) [5]. Two-carrier Drude fits additionally reveal a light hole transport mobility of ~1400 cm^2/Vs and a heavy hole transport mobility of ~230 cm^2/Vs at 3 K. By fitting the temperature-dependence of oscillation amplitude to the standard Lifshitz-Kosevich formula, effective masses of the light and heavy hole are obtained.

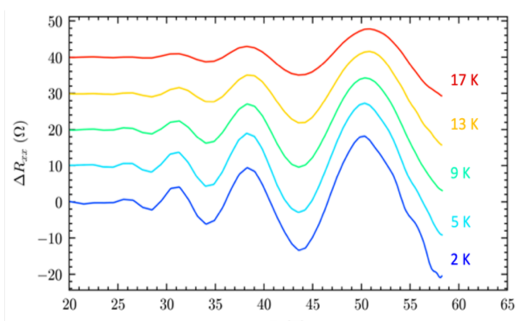

Fig 1. SdH oscillations in longitudinal resistance with polynomial background subtraction. Curves are vertically offset for clarity.

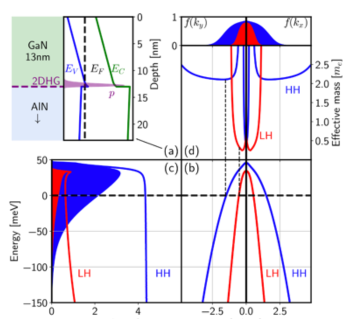

Fig 2. 6x6 multi-band k.p calculations of a GaN/AlN heterostructure. Reproduced from Ref. 5.

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