Microwave-modulated Shubnikov-de Haas oscillations in a two-dimensional GaN electron gas

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One of the most commonly used techniques to characterise the transport properties of a semiconductor system is the Shubnikov-de Haas (SdH) measurement. Observations of the SdH oscillations requires that the thermal energy and the scattering-induced energy broadening be much smaller than the Landau level separation. To detect SdH oscillations, the measurement needs to be performed in the low-temperature, high magnetic field regime. Moreover, the sample mobility has to be relatively high. To date, many experimental techniques have been developed to enhance the sensitivity of the conventional SdH measurements. For example, in the carrier-modulated technique, the carrier density is modulated by a chopped laser beam [1,2]. Using the carrier modulation technique, one is able to enhance the SdH sensitivity. However, excess carriers generated by the laser beam make the determination of the carrier concentration very difficult.

In this paper, we report a novel technique utlising microwave modulation to drastically enhance the SdH sensitivity. Most importantly, using this method we are able to keep the carrier density constant. For our measurement set-up, the microwave is guided to the sample surface by a microwave coaxial cable. In this way, no cavity and no special waveguide are needed. Figure 1 shows that the onset of the SdH oscillations is 4.2 T for the conventional SdH measurements whilst the onset of the microwave-modulated measurements is lowered to 3.2 T. In our system, the mechanism of the enhanced SdH amplitude is ascribed to the hot-carrier effect induced by microwave absorption and the suppression of the non-oscillatory background. The electrons near the Fermi level absorb the incident microwave and become hot carriers. Under chopped microwave modulation [3], the SdH amplitude can be greatly enhanced, as clearly shown in figure 1. Figure 2 shows the microwave modulated SdH measurements at different powers. We can see that the SdH amplitudes increase with increasing microwave power. This result further substantiates that the hot carrier effect enhances the SdH patterns in our system. Our novel technique is suitable for studying many semiconductor systems in which moderate mobilities and heavy effective masses (rapid damping SdH amplitudes) are frequently encountered.

References:

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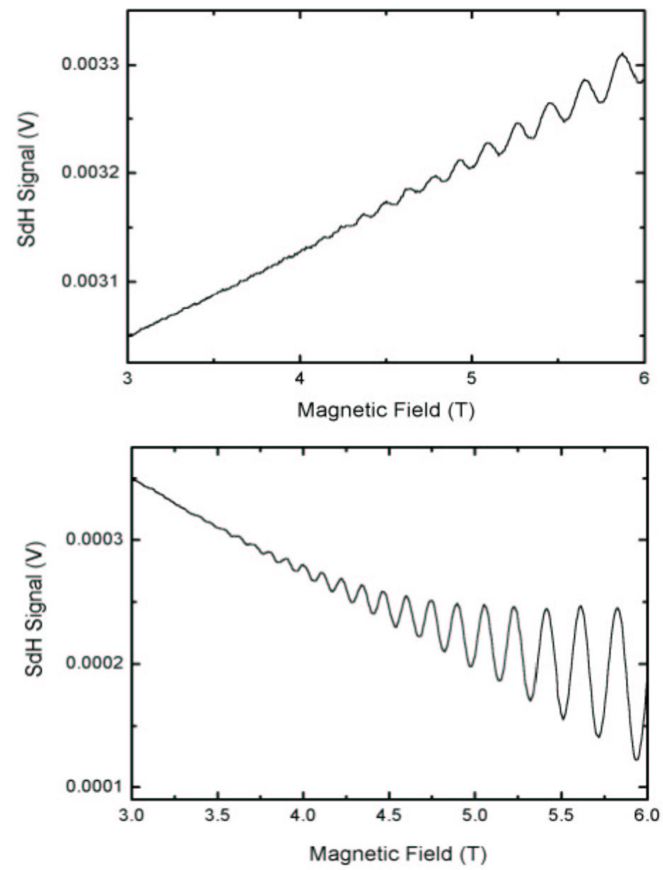

Figure 1: Top panel: Conventional SdH measurements taken at T=4.3 K.
Bottom panel: The microwave-modulated SdH measurements taken at T=4.3 K. The microwave frequency is 3 GHz.

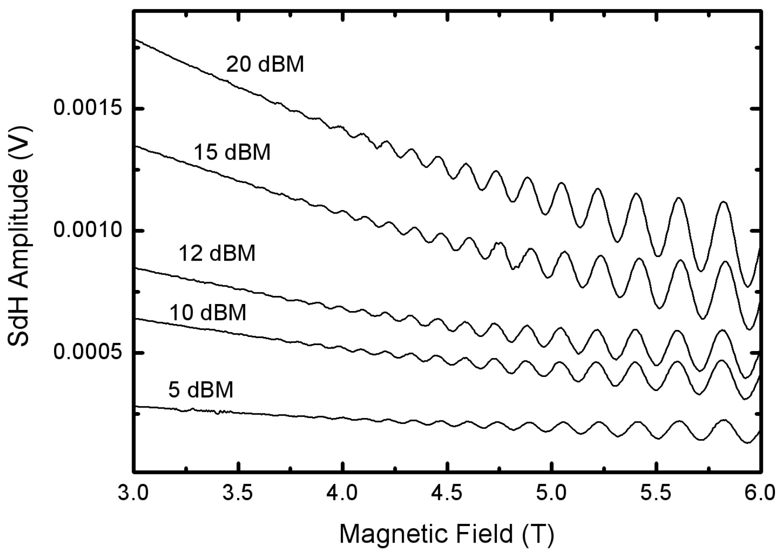

Figure 2 Microwave-modulated SdH measurements at various microwave powers. The measurement temperature is 4.3 K and the microwave frequency is 4 GHz.