Bonding of GaN with Si using SeS_2 and Laser Lift-off

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The GaN crystal structure, combined with the high growth temperatures makes deposition of high-quality material directly onto common semiconductor substrates such as Si or GaAs very difficult. Sapphire is commonly employed as a substrate due to its refractory properties. The many advances in GaN epitaxial growth have resulted in high-quality GaN material on sapphire substrates. Despite the recent improvements in GaN thin-film quality, the sapphire substrate still inhibits LED, laser and transistor device performance due to its poor thermal and electrical conductivity. On a sapphire substrate, all ohmic contacts to a GaN-based device must be made from the front surface; hence, the contacts to the first grown layers of the heterostructure suffer a lateral spreading-resistance penalty. The poor thermal conductivity of sapphire, compared to Si or SiC, also prevents efficient dissipation of heat generated by GaN-based high current devices, such as lasers and high-power transistors, thus inhibiting device performance.

A wafer bonding and thin-film lift-off process has been implemented to integrate GaN with dissimilar substrate materials, such as Si. The integration would take advantage of the high quality GaN growth on sapphire substrates and the superior thermal and electrical conductivity of Si. The goal for this approach is to be able to fabricate GaN thin films on Si substrates with the added advantage that they can be lifted off cleanly in a cheap and convenient fashion.

GaN layers were grown on sapphire (0001) substrates by MOCVD method at atmospheric pressure. Sapphire substrate was first baked at 1100^{o}C in H_2. By use of ammonia (NH_3), trimethylgallium (TMG) and SiH_4 (10 ppm), a 2 μm thick GaN layer was grown at 1050^{o}C after growth of a 0.03μm thick GaN buffer layer grown at 530^{o}C. A 1μm thick SeS_2 layer is coated on Si substrate by wet chemical treatment already reported [1]. The GaN/sapphire structure was then pressure bonded onto Si substrate at 350^{o}C for 10 minutes in a flowing nitrogen ambient. During the initial stage of the bonding, as the temperature exceeds the SeS_2 melting point, SeS_2 flows laterally to fill in any voids and encase sub micron particulates and surface asperities. The resulting bonding is strong enough to withstand the subsequent thermal and mechanical shock from the laser lift-off process. The sapphire-nitride interface was irradiated with 308nm excimer laser irradiation (Xe-Cl). Single-pulse radiation results in metallization of the interfacial nitride, as result of which the nitride/Si epilayer detaches from the sapphire and now adheres to the host substrate. The advantage of our process is that no epoxy is needed to hold the substrate since the bonding between GaN and Si is very strong and also other techniques use Pd and In as a bonding agent between GaN and Si and hence temperature in excess of 200^{o}C would destroy the bonding during the laser lift-off. Figure 1 is the process flow for liftoff and transfer of GaN. Adopting this process we were able to transfer 3mm x 7mm GaN films from sapphire substrate to Si substrate. The transplanted film was smooth and bonding occurred over the entire length and breadth of the sample. The surface morphology taken under Nomarski conditions of the transplanted film is shown in figure 2. The surface was smooth and also mirror like.

Photoluminescence taken at room temperature exhibited peaks at higher wavelengths in addition to the main band edge. The peak intensity at higher wavelength is increased with increasing the radius of laser irradiation and should be originated from the nitrogen vacancy.

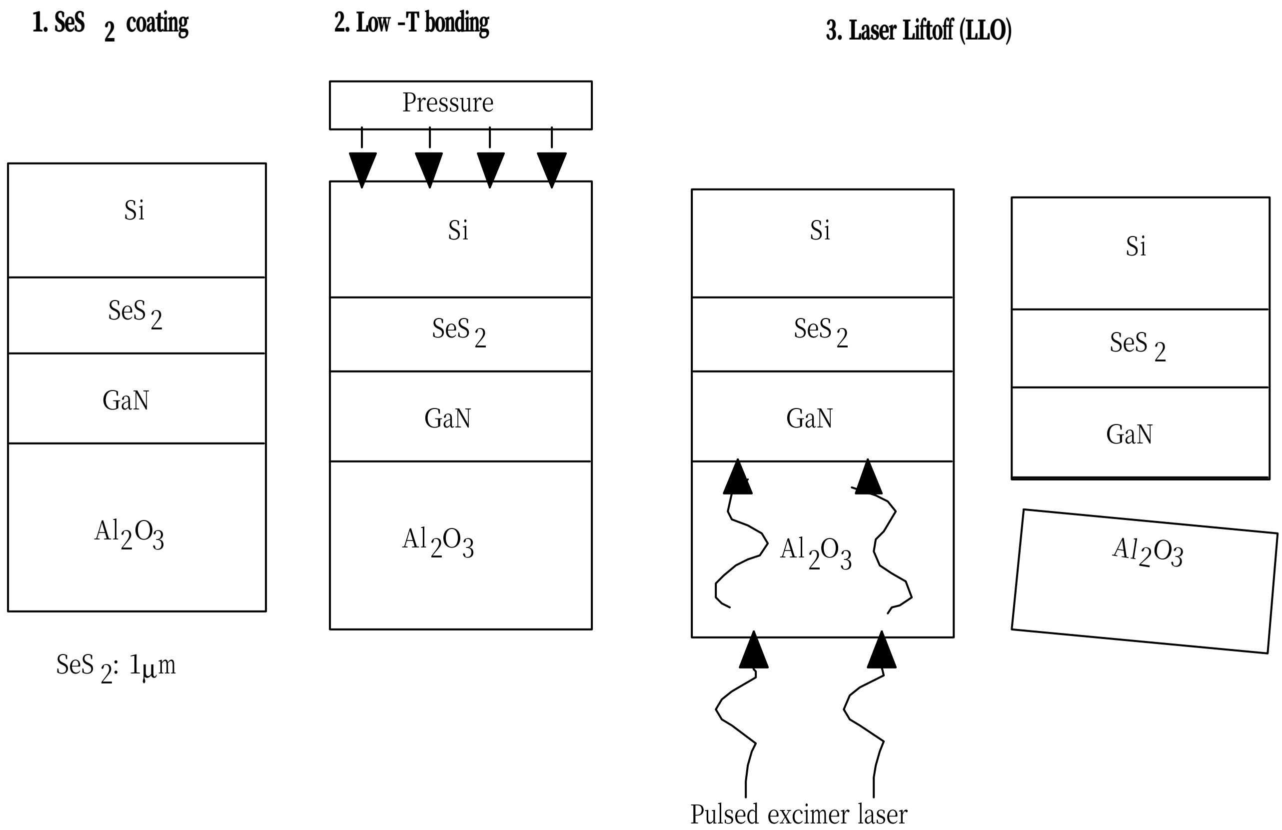

Figure 1. Process flow chart of the bonding and laser lift-off

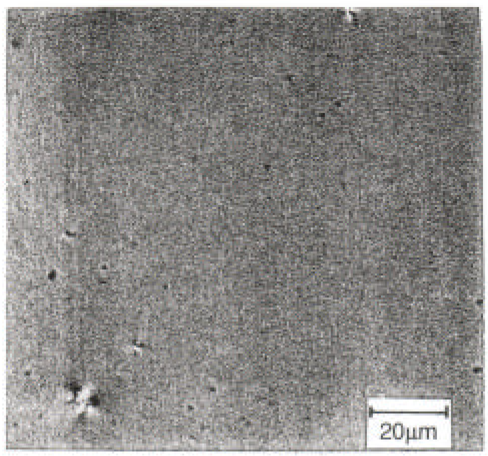

Figure 2. Nomarski surface morphology of GaN bonded to Si

Thus we hope the eventual integration of GaN with Si using our bonding and laser lift-off process will open more research avenues and the possibility of integrating GaN-based devices fabricated onto Si substrate.

1. J. Arokiaraj, T. Soga , T. Jimbo and M.Umeno., Appl. Phys. Lett. 75 (1999) 3826-3828