

Mass production QF-HVPE of GaN-on-GaN system

Researchers claim record mobilities of $1591\text{cm}^2/\text{V-s}$ and $18,175\text{cm}^2/\text{V-s}$ at room temperature (295K) and low temperature (35K), respectively.

Sumitomo Chemical Co Ltd in Japan has developed a mass-production quartz-free hydride vapor phase epitaxy (QF-HVPE) system capable of fabricating gallium nitride (GaN) with a claimed record mobility both at room temperature and low temperature [Shota Kaneki et al, Appl. Phys. Express, v18, p055502, 2025]. The material was demonstrated both on 4-inch freestanding GaN substrates and 6-inch GaN-on-sapphire templates.

The Sumitomo team was particularly concerned to reduce carbon contamination, which has been associated with mobility collapse below theoretical expectations. HVPE avoids the presence of carbon that is unavoidable in the metal-organic (MO)VPE conventionally used in growing high-quality GaN layers in mass production. Avoiding quartz (crystalline SiO_2) in the system construction enables better control of silicon (Si) doping used to achieve n-type, electron majority transport.

The team suggest that their work could lead to GaN-on-GaN power devices for applications that require breakdown voltages greater than 10kV, as needed for power drive and inverter systems used in electric vehicles and drones.

The team describes the motivation for the switch to electric-powered transportation: "Achieving carbon neutrality is strongly demanded for realizing the sustainable development goals developed in response to the rapid progression of global warming, which has led to frequent extreme weather and disasters around the world in recent years. Because thermal power generation accounts for more than 60% of the world's electricity generation, the proliferation of renewable energy and the reduction of losses through high-efficiency power conversion systems are essential to achieve carbon neutrality."

GaN has a wide bandgap that enables high breakdown voltages in semiconductor device structures.

The QF-HVPE was performed at 1050°C , giving a growth rate of $1\mu\text{m}/\text{minute}$. This compares very favorably relative to the typical $\mu\text{m}/\text{hour}$ rates for MOVPE. The Ga and N chemical elements were sourced from ammonia (NH_3) and gallium monochloride (GaCl). Dichlorosilane (H_2SiCl_2) was used for Si doping. These active components were carried to the growth front in a mix of hydrogen and nitrogen gases. The researchers grew GaN layers with a target $4\times 10^{15}/\text{cm}^3$



Figure 1. Six-inch GaN template on sapphire substrate fabricated using QF-HVPE system.

silicon concentration ($[\text{Si}]$) on substrates with 4- and 6-inch diameters. The 4-inch substrate was free-standing GaN, while the 6-inch-diameter layer was grown on a GaN-on-sapphire template (Figure 1).

The researchers used secondary-ion mass spectroscopy (SIMS) to show that the mass-production QF-HVPE system eliminated carbon and oxygen contaminations as far as possible. In particular, the concentrations of these two elements was found to be below the detection limits of their analysis: $1\times 10^{14}/\text{cm}^3$ for [C], and $5\times 10^{14}/\text{cm}^3$ for [O]. The researchers comment that this improves on a prototype QF-HVPE system reported in early 2024 that managed to reduce carbon contamination to a just measurable $1.4\times 10^{14}/\text{cm}^3$.

The researchers report: "Each sample exhibited almost featureless surfaces without pits or hillocks and a smooth as-grown surface with regularly arranged steps, as evaluated from an atomic force microscopy image and consistent with previous reports. Because the surface morphology directly affects the leakage current of devices, this flat surface without pits and hillocks is favorable for the stable operation of GaN devices."

According to Fourier transform infrared (FTIR) spectral analysis the layers were $14.1\mu\text{m}$ thick.

Unlike conventional HVPE, which suffers from large thickness variations, the Sumitomo researchers found that their layer thicknesses had just 3.4% standard deviation, "similar to that of an MOVPE-grown epitaxial film". The growth on the 6-inch GaN/sapphire template had a larger, but "reasonable" thickness standard deviation of 4.4%. The team reports that 6-inch freestanding GaN substrates are under development.

The excess of donors over acceptors ($N_D - N_A$) in the material was assessed using non-contact capacitance-voltage (C-V) measurements. Samples grown with metal-organic vapor phase epitaxy (MOVPE) had average $N_D - N_A$ values of $4.3 \times 10^{15}/\text{cm}^3$, compared with $6.8 \times 10^{15}/\text{cm}^3$ for the QF-HVPE sample. The MOVPE sample suffered from a high variability of $N_D - N_A$ with 14.3% standard deviation. By contrast the standard deviation for the QF-HVPE GaN layer on 4-inch freestanding substrate was only 3.0%. The team suggests that the problem for the MOVPE sample was the off-angle-dependent C-incorporation efficiency, based on previous work. The carbon-free nature of the QF-HVPE avoids this problem.

The control of carrier concentration was demonstrated by varying $[\text{Si}]$ during the last $2.4\mu\text{m}$ growth in 600nm steps (Figure 2). The dependence $N_D - N_A$ on $[\text{Si}]$ was found to be linear over the wide range 10^{14} – $10^{18}/\text{cm}^3$.

The researchers comment: "Control of the carrier concentration in epitaxial layers grown by MOVPE is known to be poor when the carrier concentration is less than $1 \times 10^{16}/\text{cm}^3$ because of C-induced carrier compensation. On the contrary, the high purity of QF-HVPE-grown layers, in which the C contaminant concentration was less than $1 \times 10^{14}/\text{cm}^3$, led to high linearity even at carrier concentrations less than $1 \times 10^{16}/\text{cm}^3$. Given that many power devices operate at voltages above the kilovolt range, controlling the carrier concentration in the concentration range below $1 \times 10^{16}/\text{cm}^3$ is essential."

Hall-effect measurements (Figure 3) showed record mobility values at room temperature (295K) and low

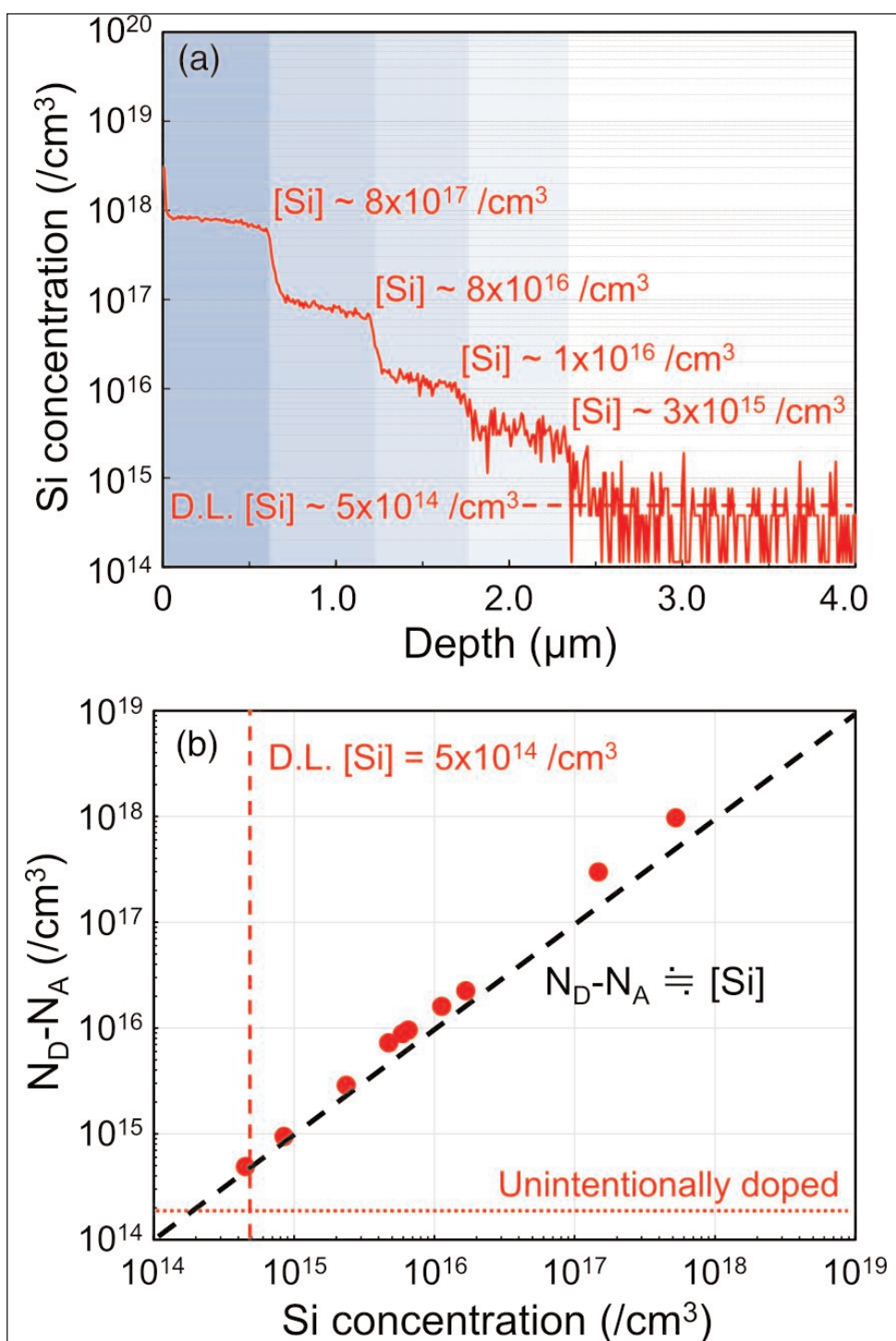


Figure 2. (a) Depth profile of $[\text{Si}]$ obtained by SIMS analysis, $[\text{Si}]$ varied stepwise every 600nm; epitaxial layer deeper than $2.4\mu\text{m}$ from surface was unintentionally doped. (b) Relationship between $[\text{Si}]$ and $N_D - N_A$ of QF-HVPE-grown layer on freestanding GaN substrate from non-contact C-V analysis.

temperature (35K) of $1591\text{cm}^2/\text{V-s}$ and $18,175\text{cm}^2/\text{V-s}$, respectively.

The researchers comment: "Although various research groups, including our group, have reported an anomalous decrease of the electron mobility in GaN layers compared with the theoretical value — a phenomenon known as mobility collapse — the present data can be well fitted using the traditional mobility theory."

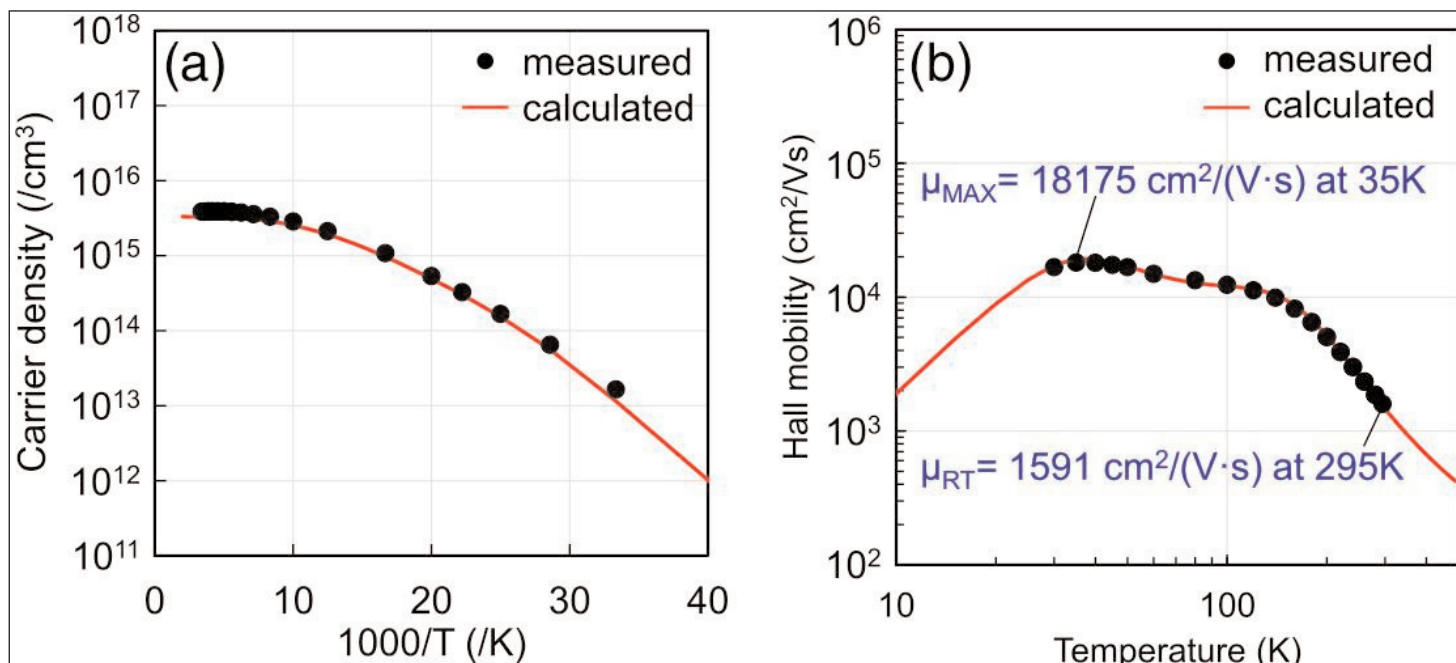


Figure 3. Measured and calculated temperature dependence of (a) carrier density and (b) Hall mobility for QF-HVPE-grown GaN bulk crystal. Black closed circles and red solid lines represent acquired data with curves fitted using traditional mobility theory.

The mobility collapse has been explained by carbon-induced scattering, and Sumitomo's results on its low [C] material supports this assertion. Photoluminescence experiments also showed spectra without blue and yellow emissions associated with carbon contamination. ■

<https://doi.org/10.35848/1882-0786/adce53>
https://www.semiconductor-today.com/news_items/2024/jan/sumitomo-250124.shtml

Author: Mike Cooke

REGISTER
for *Semiconductor Today*
free at
www.semiconductor-today.com