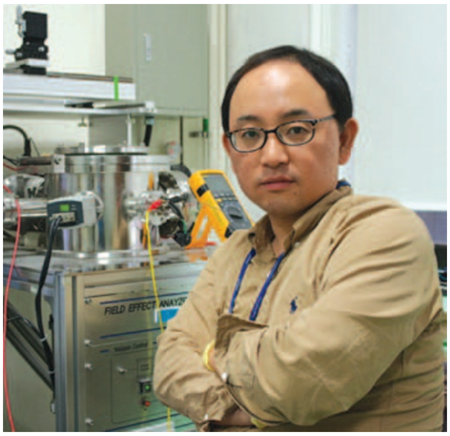
GaN-on-glass success

The successful growth of GaN-based LEDs on amorphous glass avoids the size and cost limitations of a sapphire substrate, says Jun Hee Choi from the Samsung Advanced Institute of Technology in South Korea.

What is your motivation behind your research?
At present, GaN is one of the most important materials for making high-efficiency, long-lifetime blue LEDs. Another promising GaN-based application is for producing white LED light, where yellow phosphors are excited by a blue LED. Even though GaN-based LEDs are in high demand for such applications, the sapphire substrate on which the LEDs are fabricated is limited to diameters of around 5 cm because of difficulties in the crystal growth of sapphire. To circumvent this problem, researchers have been intensively developing GaN LEDs grown on silicon substrates. Although the lattice mismatch between GaN and silicon is larger than that between GaN and sapphire, using silicon allows us to enlarge the growing surface to diameters of up to 30 cm. However, we want to extend it even further. Currently, the maximum size of a commercially available glass substrate is 240 cm × 280 cm, which is around 100 times that of the largest available silicon substrate. If we can fabricate GaN-based LEDs on such a large glass substrate, the cost per unit area will be extremely low. The problem is that the single-crystal growth of GaN on an amorphous substrate has not been possible until now.

How did you get the idea for your growth technique?
Our inspiration came during experiments. When we began our project, we had no clue how to proceed. Even though single-crystal growth of GaN on an amorphous material sounded impossible, we tried many times. The results were awful at first. The grown crystal was polycrystalline and randomly oriented. We wanted to find out how to grow GaN epitaxially regardless of the crystal size and growth direction on the substrate. One day, we found some faceted crystals that measured around a micrometre in size. This gave us the inspiration to find selective growth techniques for growing GaN nanorod or pyramid arrays; we thought that the realization of single-crystalline GaN pyramid arrays would be possible by achieving spatial confinement on the substrate.


JUN HEE CHOI

What makes it possible to grow nearly single-crystalline GaN?
So far, most techniques for growing GaN nanostructures control the growth direction by using a substrate such as GaN, silicon or sapphire. In these techniques, the lattice constant of the substrate must be close to that of the grown crystal. In our method, we control the growth direction by depositing a thin layer of titanium on the glass substrate. The titanium layer orients the *c*-axis of GaN almost perpendicularly to the substrate. But the growth is still random in the plane of the substrate, so we apply a hole-patterned SiO_2 layer on top of the titanium to introduce confinement. Thus, the competition for crystal growth occurs in each individual hole. As a result, only a few crystals — those whose *c*-axes are oriented perpendicular to the substrate — survive in each hole. The grown GaN pyramid is nearly a single crystal, as confirmed by scanning electron microscopy and transmission electron microscopy.

What difficulties did you need to overcome?
The choice of materials for the pre-orienting layer was difficult. In the beginning, we examined the feasibility of using ZnO and AlN, both of which have small lattice mismatches with GaN. By depositing layers of ZnO or AlN on a glass substrate, we were able to demonstrate perpendicular alignment of crystal *c*-axes to the substrate. However, we faced two problems. First, the ZnO layer decomposed during exposure to a gas mixture (NH_3 + H_2) at temperatures above 600 °C — the minimum temperature required for GaN growth. Second, AlN is unsuitable for vertical current injection in electroluminescent devices because it has a large electrical resistance even when only 50 nm thick. We therefore examined the feasibility of using titanium, zirconium or hafnium, which all have small lattice mismatches with GaN. In the end, we decided to use titanium as a pre-orienting layer because it is easy to deposit on a glass substrate by electron-beam evaporation. In addition, titanium is thermally and mechanically stability and exhibits high electrical conductivity. These features are absolutely imperative for the pre-orienting layer.

How are your findings likely to impact optoelectronic device development?
GaN-based optoelectronic devices will benefit significantly from our growth technique, particularly given the ease at which we can extend the upper size limit of the GaN growth area. Our findings can be used, for example, in the development of high-efficiency solar cells and photosensors based on GaN–$In_xGa_{1-x}N$ rod arrays on large-sized glass substrates.

What are your plans for future work in this area?
In the near future, we aim to further improve the efficiency and lifetime of GaN LEDs on 2-inch-diameter fused-silica glass. We also plan to keep on improving the crystalline quality of the GaN pyramid arrays by optimizing the design of the pre-orienting layer. In the long term, our dream is to customize ordinary glass. It would be wonderful if glass windows could emit light or display videos. However, this requires a number of other technological breakthroughs, such as lowering the GaN growth temperature to around 700 °C and developing a metal–organic vapour deposition facility that is scalable to such large-sized glass substrates.

INTERVIEW BY NORIAKI HORIUCHI

Jun Hee Choi and co-workers have an Article on GaN-on-glass LEDs on page 763 of this issue.