NTT Press Releases

(Press release)

April 11, 2012

Development of a groundbreaking process for release of GaN-based devices from substrates

-- Towards flexible LED, UV-sensitive high efficiency solar cell, and hybrid CMOS --

Nippon Telegraph and Telephone Corporation (NTT, CEO: Satoshi Miura, Tokyo) are pleased to announce a success in developing a groundbreaking process for release of GaN-based thin-film devices[*1] from substrates, where an extremely thin layer of boron nitride (BN) is grown between a sapphire substrate and the GaN-based semiconductor and works as a release layer. This process is named MeTRe (Mechanical Transfer using a Release layer) method.
This technology facilitates the transfer of the resulting nitride structures (typically a few μm thick) to more flexible and affordable substrates. Accordingly, preparation of novel devices such as very thin LEDs, transparent solar cells sensitive only to UV light, and highly-functional hybrid CMOSs becomes possible. This development was achieved based on our well matured film growth technology for the nitride semiconductor thin films, which has been developed and accumulated in NTT Basic Research Laboratories (NTT Atsugi R&D Center).
This achievement will be reported in “Nature” magazine on April, 12.

1. Background

GaN-based semiconductors have a wide range of applications such as high-power electronic devices for wireless communications, visible light sources for illumination and signal, and UV light sources for sterilization.
At present, those devices are fabricated by processing the GaN-based semiconductor thin films together with single-crystalline substrates. However, only limited materials can be used as the substrates since they must be stable at the GaN thin film growth temperature (typically as high as 1000°C) and have similar crystal structure to GaN. In addition, some potential applications of the thin-film devices have been hampered by the substrates, whose typical thickness is 100 times as large as that of the thin-film devices. If the thin-film devices alone can be released from the original substrates and transferred onto any other substrates (Fig. 1), the thin-film devices may have a wider field of application (Fig. 2). Accordingly, a tremendous worldwide effort is underway to develop such detachment processes (e.g., Fig. 3).
We, NTT Labs., have been investigating growth of layered BN thin films toward a view to utilizing it as a release layer between the substrates and the GaN-based thin-film devices. The key point is that the BN takes a layered structure, same as Graphite, which is unique among the nitride semiconductors.

2. Summary of the development

NTT has newly developed a technique of growing high-quality layered BN thin films on sapphire substrates and also growing high-quality GaN-based thin films on BN. Since, in this structure, the cleavable BN plays the role of a release layer, one can easily detach the GaN-based thin-film devices from the sapphire substrates and transfer them to other substrates **[MeTRe (Mechanical Transfer using a Release layer) method: Fig. 4]**.
With this technology, the devices can be transferred without any laser beam machining or chemical treatment, either of which is required in the conventional methods (Fig. 3). Additionally, surface flattening processes also become unnecessary after the removal of the thin-film devices. Furthermore, MeTRe method is better suited for a large-area processing, hopefully up to the range of one meter. Accordingly, a significant reduction of the fabrication cost is expected.
We have demonstrated a very thin LED, in which a detached thin-film device is sandwiched by two laminate films (total thickness is as small as 0.2 mm, Fig. 5), indicating that this technology has opened a door for GaN-based flexible devices. A solar-cell application also looks promising since power generation efficiency can be improved by attaching UV-sensitive GaN-based solar cells onto conventional Si-based ones. The characteristic feature of GaN, transparent but UV-sensitive, makes it feasible to attach the GaN-based solar cells on windows, which can cut hazardous UV light while generating power.

3. Technological key points

(1) Growth of high-quality BN thin films (Fig. 6)

It has been difficult to grow high-quality BN films on single crystal sapphire substrates mainly because of their substantially different crystal structures. However, by systematic optimization of the growth parameters in Metal-Organic Chemical Vapor Deposition (MOCVD)[*2] process, including the substrate temperature and growth rate, we have succeeded in preparing high-quality epitaxial BN thin films on sapphire substrates.

(2) Growth of high-quality GaN thin films on layered BN (Fig. 7)

We have found that high-quality GaN thin films can be grown on the layered BN thin films by inserting a buffer layer of $Al_{1-x}Ga_xN$. This is most likely due to a higher affinity of the Al-contained nitrides for BN. Eventually, our wish of growing high-quality GaN thin films on sapphire with a BN release layer in between them was accomplished.

4. Prospects

Now the GaN-based thin-films devices can be detached from substrates much easier than they could previously. Further investigation is currently underway to improving the performance of the conventional solar cells (Fig. 8) and the functionality of the CMOS-based devices as well as increasing the area of the detachable devices.

Terminology

*1: GaN-based thin-film devices

We generically call GaN, AlN, InN, and their alloys ($Al_{1-x}Ga_xN$, $In_{1-x}Ga_xN$) GaN-based semiconductors. In order to create electronic devices (e.g., transistor) and optical devices (e.g., LED), stacking thin film layers of GaN-based semiconductors and microfabrication are necessary. We call such functional devices GaN-based thin-film devices.

*2: Metal-Organic Chemical Vapor Deposition (MOCVD)

MOCVD is a widely used chemical vapor deposition method of epitaxial growth of materials, especially compound semiconductors such as GaAs, InP, and GaN. By supplying source gases of the constituent elements into a reactor and giving rise to chemical reaction on substrate surfaces, single-crystal thin films of target materials can be grown on the substrates.

Attachment·Reference

- Fig.1: What is a transfer technique ?
- Fig.2: Merits of transfer techniques: unlimited choice of substrate
- Fig.3: Comparison of transfer methods: ours vs. conventional ones
- Fig.4: Schematic illustrations of the device design, release and transfer process by MeTRe method
- Fig.5: LED prototype at room temperature
- Fig.6: (Key point 1) Growth of high-quality BN thin films
- Fig.7: (Key point 2) Growth of high-quality GaN thin films on layered BN
- Fig.8: Prospects for future applications: solar cells

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