Electrical Characterization of Semipolar Gallium Nitride Thin Films

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Abstract:

Considerable economic and environmental savings will be achieved through the successful development of high efficiency solid state lighting sources. Recent breakthroughs have been made in the development of GaN based blue, green, and white light emitting diodes (LEDs) and blue laser diodes (LDs). Typically, GaN optoelectronic devices are heteroepitaxially grown on C-axis oriented sapphire substrates using techniques such as metalorganic chemical vapor deposition (MOCVD). Such structures suffer from polarization-induced internal electric fields along the {0001} growth direction which limit the radiative efficiency of the device. Recent theory suggests that growth of semipolar GaN orientation will reduce these internal fields and improve device performance. However, the successful growth methods for semi-polar GaN thin films are still under development.

GaN crystals grown under different conditions call for characterization techniques such as measuring the Hall Effect using the Van de Pauw technique, a method of measuring the resistivity and Hall coefficient on lamellae of arbitrary shape. It is from these properties that the mobility and concentration of charge carriers are derived. The two variables allow for the comparison of the quality of different crystals, leading to the successful optimization of growth conditions for semi-polar GaN thin films.

Introduction:

Solid materials are classified by the way the atoms are arranged. Materials with atoms placed in ordered structure are called crystalline as opposed to amorphous. GaN and its alloys are most stable in wurtzite crystal structure, which is based on the hexagonal form of zinc sulfide (ZnS), and is described by two or three basal axis on the same plane, each 120° apart respectively, and each normal to the same c-axis. GaN and its alloys grown along this c-axis possess spontaneous polarization parallel to the plane vector, and the wurtzite structure possesses piezoelectric polarization. Most of the current optoelectronic devices have c-plane quantum wells that suffer from the effect of the strong internal electric field caused by the spontaneous and the piezoelectric polarizations. This reduces the recombination efficiency by causing spatial separation of holes and electrons.

A combination of techniques could reduce the internal electric field. First technique is to grow GaN devices on semipolar planes. These planes are referred by two non-zero values in the basal axis in the Miller indices h, i, and k, and another non-zero value describes the c-axis ({h i k c}). Common examples include {1013}, and {1011} planes. The plane vector in this case points at some degrees away from the c-axis. Due to this, the spontaneous polarization is reduced. Second technique is to grow heterostructure GaN that has thin layer of ternary and quaternary GaN compounds such as AlGaN, InGaN, and AlInGaN. Due to difference in lattice constants, a layer of InGaN on GaN produces compressive strain, while a layer of InGaN produces tensile strain. These strains are the cause of piezoelectric polarization, and by alternating layers, the types of strain counteract each other reducing the piezoelectric polarization.

GaN crystals are grown epitaxially. In metalorganic chemical vapor deposition (MOCVD), substrates provide close lattice match to GaN. Common substrates are spinel ($MgAl_2O_4$) and sapphire (Al_2O_3). In a vacuumed space, the substrate sits upon a spinning hot plate. A mixture of carrier gases and metalorganic gases supplies the gallium or its compounds, while the gaseous ammonia supplies the nitrogen. GaN crystals are formed when the metalorganic mixture and the ammonia reacts and bonds to the surface of the substrate, creating layers of GaN materials having crystal orientation similar to the orientation of the

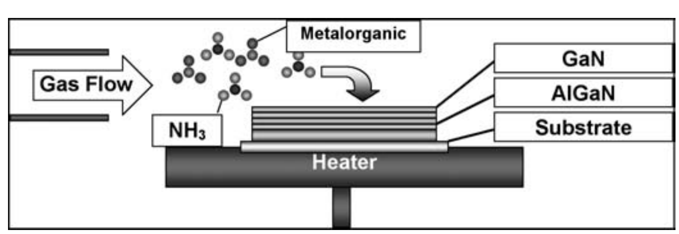

Figure 1: MOCVD.

substrate (Figure 1). This is known as a heteroepitaxial relationship.

Procedure:

The Van de Pauw method offers an alternative and easier way to measure the resistivity and Hall coefficient on lamellae of arbitrary shape, rather than on the difficult Hall Effect sample bars. These two properties at different temperatures are essential part of the electrical characterization of semiconductor materials. It is from these values the mobility and charge carrier concentration are derived [1].

After a wafer of GaN crystal is grown, it is cleaved into sample squares. A sample should be a flat lamella completely free of holes. The metal contacts are placed as close to the corners of the squares as possible to reduce errors (Figure 2). Contacts are made with indium dots or gold deposition to provide electrical conduction for the Hall Effect measurement.

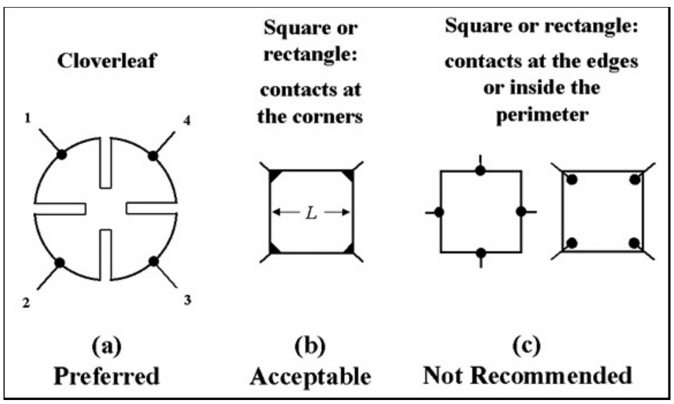

Figure 2: Sample shape and position of contacts.

Results and Conclusion:

Semipolar GaN crystals were grown currently with a general outline of growth parameters in pressure between 400 to 1000 torrs, and temperature between 600°C to 1400°C. Suitable substrate can increase the stability of GaN growth and reduce the variation in temperature and pressure for specific semipolar planes.

Surprisingly, despite having the same temperature and pressure, samples grown using different carrier gases produced different surface morphology as shown by the optical microscope (Figure 3, 4). These samples are then characterized by the Hall Effect measurement. Using hydrogen gas carrier seems to produce higher mobility in crystal. However, more data is required to confirm this condition.

Future film optimization techniques include growth on nucleation layers (NL). NL employs the use of polycrystalline nitride material deposited at a thickness of 100 Å to 2000 Å before the growth of GaN. While the physics of how NLs improve the surface morphology is not well understood, the advantage of NLs on improving surface morphology is broadly practiced on c-plane growth. However, use of NLs in GaN semipolar growth has not yet been previously achieved.

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References:

[1] I. J. Van der Pauw. Philips Technical Review, vol. 26, 260, 1958.

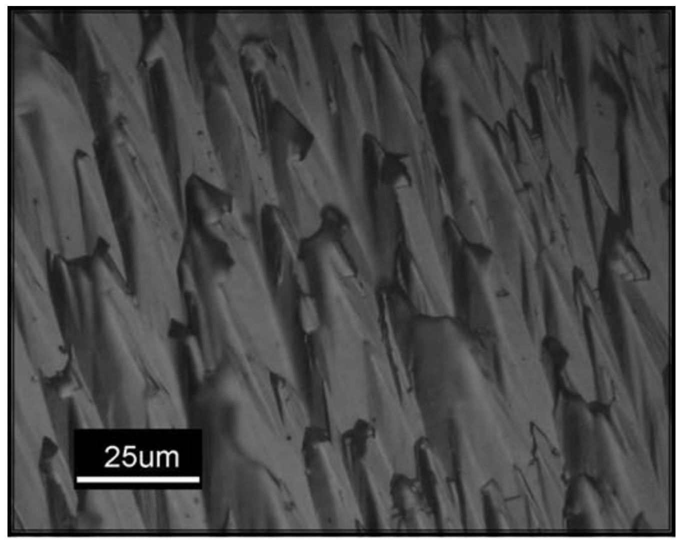

Figure 3, above: Hydrogen gas carrier.

Figure 4, below: Nitrogen gas carrier.