【Grant-in-Aid for Scientific Research (S)】

Departure from conductivity control with impurity doping in widegap semiconductors

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Purpose and Background of the Research

●Outline of the Research

Widegap (over 4eV) nitride-based semiconductors are expected to realize various optoelectronic devices, such as deep UV LEDs for COVID-19 inactivation, toward energy-saving, safe and secure society. Unfortunately, conventional “impurity doping” does not work anymore in such widegap semiconductors. In this study, a novel conductivity control of “polarization doping” and “tunnel junction” which do not depend on the impurity ionization energies will be systematically established. Hall measurements with polarization-doped samples and investigations of mechanisms in low-resistive GaN tunnel junctions will be carried out. Finally, a standard of conductivity control with polarization doping and tunnel junctions will be established by demonstrating various next-generation widegap optoelectronic devices.

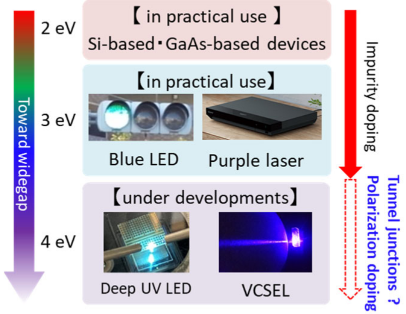
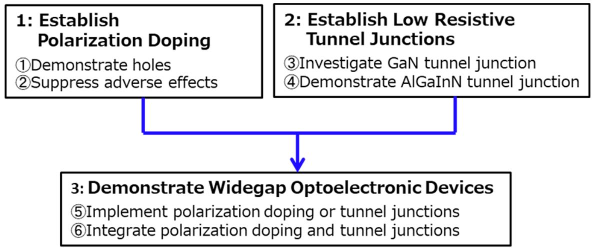


Figure 1. Semiconductor devices and conductivity control techniques



1: Establish Polarization Doping
①Demonstrate holes
②Suppress adverse effects

2: Establish Low Resistive Tunnel Junctions
③Investigate GaN tunnel junction
④Demonstrate AlGaInN tunnel junction

3: Demonstrate Widegap Optoelectronic Devices
⑤Implement polarization doping or tunnel junctions
⑥Integrate polarization doping and tunnel junctions

Figure 2. Purpose of this study

●Polarization Doping

This technique is a carrier generation technique to accumulate to polarization charges at hetero interfaces, not depending on so-called ionization energies. So far, no direct evidences, such as hole generation in AlGaN with high AlN mole fraction, are obtained.

Issues: Are holes really generated to the same concentration as polarization charges ?

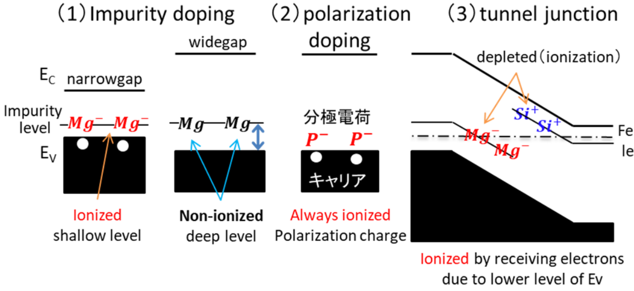


Figure 3. Schematics of fundamentals in polarization doping and tunnel junctions

●Tunnel Junctions

Even though impurity doping is used, ionizations in depletion regions of tunnel junction occur regardless of ionization energy values. Such tunnel junctions allow to use low-resistive n-type cladding layers instead of high-resistive p-type cladding layers. Somehow a broad interface at a GaN tunnel junction is very useful to obtain low resistivity, which contradicts to the sharp interface as the textbook describes.

Issues : What is the origin of the low resistivity even with the broad interfaces ?

●Widegap Optoelectronic Devices

Polarization doping and tunnel junctions are utilized in some widegap optoelectronic devices, such as deep UV LEDs for virus inactivation (AlGaN>4eV) and VCSELs for retinal scanning displays (AlInN~4eV). In most cases, the devices with polarization doping and tunnel junctions are not superior to those with impurity doping.

Issues : Is it really possible to utilize polarization doping and tunnel junctions effectively in device structures ?

Expected Research Achievements

●Establish Polarization Doping

①Demonstration of holes: Investigate AlN mole fraction and thickness dependences on hole generations in graded AlGaN Hall samples with p-AlGaN contact layers.

②Suppression of adverse effects: In order to suppress electron leakage due to the opposite polarization charges (adverse effects), “impurity-doped graded interfaces” and “adjacent active layers” will be developed.

●Establish Low Resistive Tunnel Junctions

③Investigation of GaN tunnel junctions: investigate mid-gap states at tunnel junction interfaces by photothermal deflection spectroscopy and correlate with resistivity.

④Demonstration of AlGaInN tunnel junctions: Based on the above understanding, various low-resistive AlGaInN tunnel junctions will be demonstrated.

●Demonstrate Widegap Optoelectronic Devices

⑤Implementation of polarization doping or tunnel junctions: The above two new techniques will be implemented in quantum shell lasers and UV lasers, where the structures are optimized for the best use of polarization doping or tunnel junctions.

⑥Integration of polarization doping and tunnel junctions: By integrating both the techniques and fabricating reversely stacked optoelectronic device structures, superior carrier injection as well as carrier generation will be achieved in deep UV LEDs, VCSELs, and edge-emitting lasers.

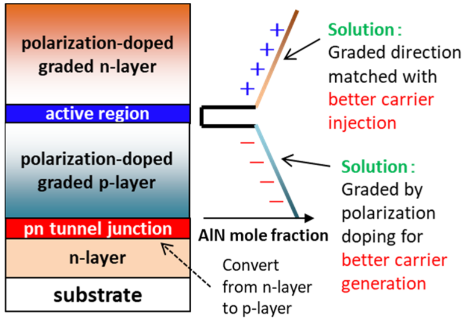


Figure 3. Integration of polarization doping and tunnel junctions

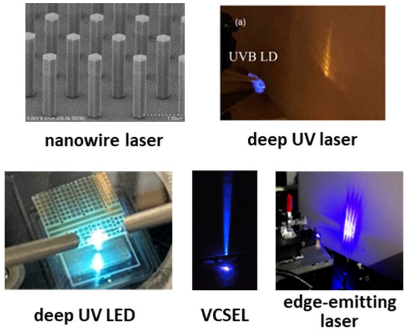


Figure 4. next-generation optoelectronic devices with polarization doping and tunnel junctions

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