Use of AlGaN Launcher in Terahertz GaN Gunn Diode

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Abstract
The terahertz frequency GaN Gunn diodes with GaN and AlGaN electron launchers are investigated by using an improved NDM model of GaN. The simulations demonstrate that there exists a shift of the oscillation mode from dipole domain mode toward accumulation mode with increased temperature, and the AlGaN launcher GaN Gunn diode can generate better power performance at stable oscillation mode than the conventional notch-doped GaN launcher Gunn diode.

1. Introduction
The outstanding power performance of GaN based Gunn diode has attracted many interests in terahertz radiation source, although the practical device fabrication is immature nowadays. This paper presents a fabrication-oriented simulation of Gunn diode with different electron launchers including notch-doped GaN launcher and step-graded Al composition AlGaN launcher. The negatively differential mobility (NDM) model of GaN and AlGaN has been improved in order to show the oscillation mode and output power of Gunn diode under the wide temperature range in simulations.

2. Description of the GaN mobility model
Based on previous NDM analytical model [1], an improved NDM model are developed in order to fit the real high-field transport of GaN and AlGaN. The fitting parameters in the models are extracted according to the previous experimental and Monte Carlo date [2-5]. For AlGaN mobility model, the modification factors of Al composition, random alloy scattering as well as the doping concentration are developed to correct the errors of previous GaN mobility model especially at high temperature. The polarization induced interface charges are also taken into account at AlGaN/GaN interface. The high-field transport characteristic of GaN at (a) 300K, (b) 450K and (c) 600K respectively by using the improved model is given in Fig. 1 with previous results as comparison. Fig. 2 shows that of AlGaN with full Al composition at room temperature.

3. Gunn diode structure for simulation
Fig. 3 gives the schedule of GaN Gunn diode with electron launcher region, where the doping and the length of n-GaN transit region is set as $1.5 \times 10^{17}$ cm$^{-3}$ and 0.6 μm respectively in order to generate the oscillation frequency over 300 GHz at dipole domain mode. Two kinds of launcher regions are investigated which include (a) the conventional notch-doping GaN launcher and (b) the novel multiple step-graded AlGaN launcher, both with the low doping of $5 \times 10^{16}$ cm$^{-3}$.

Figure 1 High-field transport characteristics of wurtzite n-GaN with doping of $\sim 10^{17}$ cm$^{-3}$ at different temperature. Note that there appear some differences in previous data because of difference in each work.
Figure 2 High-field transport characteristics of wurtzite n-AlGaN with full Al compositions $x$ and with doping of $\sim 10^{17} \text{ cm}^{-3}$ at 300K in present model.

Figure 3 Schedule of terahertz GaN Gunn diode with an electron launcher region. Using of launcher aims to reduce the ‘dead zone’ length accordingly rise the oscillation frequency.

4. Simulation results and discussions

For the GaN Gunn diode with a multiple step-graded Al composition AlGaN launcher, along the direction from cathode towards anode, a bi-step schedule of 1%-Al (0.1µm) / 8%-Al (0.1µm), a tri-step schedule of 1%-Al (0.06µm) / 8%-Al (0.07µm) / 15%-Al (0.07µm), as well as a quad-step schedule of 1%-Al (0.05µm) / 8%-Al (0.05µm) / 15%-Al (0.05µm) / 22%-Al (0.05µm)

are proposed in simulations, aimed at estimating the effect of different Al composition AlGaN/GaN heterostructure induced electric field on the oscillation performance of GaN Gunn diode. For the GaN Gunn diode with notch-doping GaN launcher, the launcher length is set as 0.2 µm.

The simulation employs the “self-exciting oscillation” method, i.e., a DC bias voltage that assures the bias electric field in the negatively differential resistance (NDR) is supplied across above Gunn diode without connecting the external RLC resonance circuit. The method can obtain the maximal output capability at optimal oscillation frequency of the Gunn diode. For the diode structure of this work, the bias is about 30-32V. A wide temperature range of 300K-500K is taken into account in simulation. Under the condition of generating stable oscillation, a fast Fourier transform algorithm is used to extract the fundamental frequency at maximal output power from 140 ps instantaneous simulation with the results shown in Fig. 4. Different oscillation modes are marked as well. It is observed that the optimal oscillation frequency decreases with the rising Al composition in AlGaN launcher when temperature is below 450K, and a gradual shift of oscillation mode from 1# dipole domain to 3# accumulation mode with the rising temperature.

Figure 4 Dependence of fundamental frequency on temperature for GaN Gunn diode with different electron launchers. Different oscillation modes are marked as well.

Figure 5 Electric field distributions in the tri-step graded AlGaN launcher GaN Gunn diode at (a) the dipole domain mode, (b) the transition mode and (c) the accumulation mode.
Although the notch-doping GaN diode generates higher frequency, the frequency changes significantly with temperature. As comparison, the sustaining of frequency and the oscillation mode is better for tri-step and quad-step Al composition AlGaN/GaN diode especially at 350K-400K that is the real operating temperature for Gunn diode because of low dc/rf conversion efficiency. It is important for the stable operation of GaN Gunn diode. To explain the oscillation mode shifting from 1# mode through 2# mode towards 3# mode with the rising temperature, Fig. 5 gives the electric field distribution in the transit region for tri-step graded Al composition AlGaN launcher diode, which is extracted from instantaneous simulation. Typical field profiles are observed for different oscillation modes. Clearly the accumulation mode can yield shorter period for electron accumulation so as to cause the higher frequency than the dipole domain mode. To show the output performance of these kinds of Gunn diodes, the simulation gives the corresponding dc/rf conversion efficiency and output power density at 30-32V bias, as is shown in Fig. 6.

Figure 6 Dependence of dc/rf conversion efficiency and output rf power density of Gunn diodes on temperature corresponding to Figure 4.

It is found that the Gunn diode with high Al composition AlGaN launcher can generate higher conversion efficiency at 350-400K than the conventional notch-doping GaN launcher diode. It must be noted that a very high Al composition is not suitable for the bulk transport Gunn diode because of rising bulk resistance and alloy scattering. When temperature is over 400K, the carrier transport degradation and the shift of NDR region towards higher electric filed require higher bias voltage to retain the generation of NDR oscillation, causing the decrease of conversion efficiency. Although the diode can generate higher frequency at accumulation mode, the oscillation is unstable and the power performance degrades significantly as is shown in Figure 6. Note that the accumulation mode at high temperature is different from the LSA mode in Gunn diode [6], so it should be avoided in real operation.

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References