DC and RF characteristics of MBE grown GaAs barrier diode

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Abstract

Schottky barriers are used extensively in high frequency switching, mixing and rectifying circuit for their good DC and RF characteristics. In this paper we report that devices measured in a double-balance mixer circuit show that the typical value of the DBS noise figure of the mixer diode is 6.1 dB at 89.5 GHz. Very good results were also observed in the 12.5, 8, 5 and 4 mm bands. However, the barrier height is virtually constant and the operations stability depends strongly on the metallurgy of the Schottky contact. In addition, properties of planar doped barrier (PDB) diodes with an n−/i/p+/i/n+ configuration grown by molecular beam epitaxy (MBE) with precise control of the barrier height, were also studied. The results of artificial tailored $I-V$ characteristics, junction capacitance and the detector application are also presented. © 2001 Elsevier Science B.V. All rights reserved.

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0. Introduction

The interest in millimeter wave integrated circuits has promoted the development of GaAs beam lead diodes for the aim of low parasitic capacitance and good mechanical strength. Mixer diode is fabricated on n−/n+ GaAs structure, which is grown on semi-insulating GaAs substrate by molecular beam epitaxy (MBE). As the mixer is modified by controlling the layer thickness precisely and reducing the series resistance, it is available at frequencies up to 100 GHz [1,2]. In this case, the frequency limitation is determined mainly by the parasitic resistance and the junction capacitance of diode. Due to the virtually constant barrier height of mixer diode, the operation stability depends strongly on the metallurgy of the Schottky contact. Moreover, interface states play a dominant role in the Schottky barrier transport properties, which can lead to undesirable hysteresis effects particular to metal–GaAs structures. MBE grown structures consisting of an n+/i/p+/i/n+ for planar doped barrier diode (PDB) have been reported [3,4], which allows precise control of the barrier height, yielding independent control of the diode's $I-V$ characteristics. The PDB diode circumvents traditional problems associated with the GaAs Schottky diode. We have demonstrated the excellent DC characteristics that can be attained through careful design, MBE growth and devices process [5,6]. In this paper, we report the DC and RF characterization of the PDB diode grown by MBE.
1. Experimental procedure

1.1. Schottky-barrier diode

Fig. 1 is the cross section of the Schottky-barrier diode. Epitaxial layers for the millimeter wave Schottky-barrier diode with n/n+ structure were grown on (001) semi-insulating GaAs substrates at 580°C. The carrier concentrations of the n and n+ epitaxial layers were in the range of $1 \times 10^{17}$ and $1 \times 10^{18}$ cm$^{-3}$, with the corresponding thicknesses of 0.2 and 1–5 μm, respectively. The device fabrication processes include the following steps: (1) etch deep moats into the GaAs; (2) fill with low melting point glass and deposit a surface layer of SiON$_x$; (3) apply the ohmic contact metallization of AuGeNi; (4) define the active area winder (diameter 2.5 μm) in the SiON$_x$; (5) deposit the barrier metal Cr–Au or TiPtAu; (6) define and electroplate the beam leads; and (7) thin from the back surface and separate the devices by etching.

Measurements of the diode characteristics were done by holding it in a position across the gap with an insulating probe pressed on the beam leads. The DC and low-frequency evaluations of the devices were carried out with the aid of a test jig consisting of a microstrip line with a suitable gap for the diode.

1.2. Planar doped barrier diode

Fig. 2 is the schematic diagram of the GaAs homojunction planar doped barrier diode (PDBD). An n$^+$/i/p$^+$/i/n$^+$ structure designed for PDB diode was grown on a Si-doped (1 0 0) GaAs. Epitaxial growth was done under arsenic-rich conditions with substrate temperature setting at 580°C. The lower n$^+$ layer and the upper n$^+$ layer were 0.5 and 0.3 μm in thickness, respectively. The n$^+$ layers were silicon-doped with carrier concentrations of $2 \times 10^{18}$ cm$^{-3}$ and the p$^+$ layer was beryllium-doped with a carrier concentration of $5 \times 10^{18}$ cm$^{-3}$. The thicknesses of the two i layers are 10 and 200 nm, respectively. The background carrier concentration of the i layers is about $10^{15}$ cm$^{-3}$. The PDBDs were fabricated as follows: (1) circular dots were defined by conventional photolithography; (2) contacts were first formed by TiPtAu electron beam electroplating; (3) they were alloyed in N$_2$ ambient for 30 s at 400°C; (4) they were defined and electroplated with pure gold; (5) circular mesas were finally formed by chemical etching down to n$^+$ substrate; and (6) devices were bonded in standard IC package.

2. Results and discussion

2.1. DC and RF frequency characteristic of the Schottky-barrier diodes

The DC characteristics of the Schottky-barrier diodes were measured by Boonton-76A electrobridge and HP-4145B semiconductor parameter analyzer. The measured parameters ($C_j$, $C_T$, $R_s$, $V_F$, $V_R$ and $n$) are summarized in Table 1. The results have demonstrated that the diodes have good consistency. As well known, the MBE growth process enables us to precisely control the
thickness and the doping concentration of the component material. We attribute this good consistency to the abrupt doping profiles in the epilayer. The low resistance n⁺ buffer layer which was inserted between substrate and active layer reduced the total series resistance. In GaAs Schottky barrier beam lead diodes, the whisker-contacted configuration was used, and this sufficiently reduced the total capacitance (junction capacitance and stray capacitance). In addition, dielectric frame structure was adopted to enhance the strength of the beam lead. Finally, a further reduced capacitance (0.02 pF) was obtained.

Devices measured in a double-balance mixer circuit show the typical values of the DBS noise figure of 6.1 dB at 89.5 GHz. Excellent results in the 12.5, 8, 5 and 4 mm wavebands were also observed. Table 2 summarizes the RF characteristics of these Schottky-barrier diodes.

However, Schottky barrier diodes exhibit several inherent limitations in higher submillimeter wave band which are mainly caused by the parasitic resistance and junction capacitance of the diodes. On the other hand, the barrier height of the diodes is virtually constant and the interface states play a dominant role in the Schottky barrier transport properties, which leads to undesirable hysteresis effects particular to metal–GaAs structures.

### 2.2. The characteristics of planar barrier diode

As shown in Fig. 2, a p⁺-type layer was inserted in an undoped region sandwiched between two n⁺-regions. We have recently demonstrated that excellent DC characteristics of the PDBD can be attained through careful design [5]. We have extended the PDB modeling to consider the case that the two intrinsic regions have different thicknesses, which results in asymmetric $I/V$ characteristics. From our model, the barrier height increases as $N_p X_p$ increases ($N_p$ and $X_p$ are, respectively, the doping level and the thickness of the p layer), and $\phi_{sei}$ goes up slightly as p-layer expands. The value of $W_{i2}/W_{i1}$ (where $W_{i2}$ and $W_{i1}$ are the thicknesses of the lower and the upper i layer) also influences the symmetry of PDBD’s $I–V$ characteristics. Fig. 3 shows that when $W_{i2}/W_{i1}$ goes up, the barrier increases significantly, and the reverse drop voltage also increases. Fig. 4 shows the $I/V$ characteristics of the planar barrier diode which are consistent with our model.

### 3. Conclusion

Schottky barrier beam lead diode has been used in microstrip mixers, and the millimeter wave characteristics are studied systematically. At 89.5 GHz the conversion loss of a balanced mixer was 6.1 dB. By varying the thickness and doping
concentration of the p⁺ and intrinsic regions, we successfully prepared planar doped barrier diodes. In addition, the barrier height and asymmetry of the structure can be varied independently. The PDBDs with optimum response and bias conditions can satisfy the application requirement of the mixers and detectors.

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References


