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Characterization of GaInP/GaAs triple barrier resonant tunneling diodes fabricated by fast atom beam etching process

M. Fukumitsu, H. Horie, N. Asaoka, M. Suhara, and T. Okumura

Department of Electrical Engineering, Graduate School of Engineering, Tokyo Metropolitan University,
1-1 Minami-Ohsawa, Hachioji, Tokyo, 192-0397 Japan
Phone: +81-426-77-1111 ext 4463,
Fax: +81-426-77-2756
E-mail: fukumitsu@device.eei.metro-u.ac.jp

1. Introduction

Resonant tunneling diodes (RTDs) are expected to realize ultra-high frequency oscillators, amplifiers and logic circuits due to their characteristics of resonant tunneling and negative differential resistance (NDR). In a general way, RTDs are classified into double barrier resonant tunneling diodes (DBRTDs) and triple barrier resonant tunneling diodes (TBRTDs) [1]. DBRTDs have two barriers and one quantum well and NDR can be realized by crossing of quantum level with conduction band edge of the emitter. In the case of TBRTDs, there are three barriers and two quantum wells and NDR can be realized by crossing of resonant levels of two quantum levels below the Fermi level of the emitter. Therefore, TBRTDs have advantage compared with DBRTDs in respect of high temperature operation and/or revealing large negative differential conductance.

On the other hand, dry etching process, such as reactive ion etching (RIE), reactive ion beam etching (RIBE), ion beam assisted etching (IBAE), and plasma etching (PE), are used to carry out ultra-fine pattering of semiconductors. Since, these technologies used ion in plasma, several kinds of radiation damage are induced in devices by high energy particles and/or charged particles. These problems become more serious as dimensions of devices are reduced, and are still unsolved [2].

Fast Atom Beam (FAB) is one of key technologies that uses electrically neutral atomic or molecular beam, and etches a sample by physical sputtering. For this reason, FAB is expected as charge buildup damage free and synchrotron radiation damage free ultra-fine processing technology [3], and especially advantage for insulators etching, because the surface of etching target does not become charge buildup.

In this paper, we first fabricated GaInP/GaAs TBRTDs by the FAB etching process and large peak-to-valley current ratio was carried out as compared with TBRTDs fabricated by wet chemical etching process.

2. Fast Atom Beam system

Figure 1 shows a configuration of the FAB etching system. Ar-ions and electrons are generated in high electric field applied between anode bars and a cathode wall. Electrons around a saddle field formed between anode bars are reciprocating by repulsion due to the cathode wall, and promote ionization of Ar-gas. On the other hand, Ar-ions are accelerated to the cathode electrode. Passing through the cathode-grid electrode, Ar-ions beat the inner wall of the cathode-grid and combine with electrons. Therefore, neutralized Ar atom beam goes straight toward a sample. In the case of our system, the opening ratio of cathode-grid is about 80 %, and the neutralization coefficient of the beam is estimated to be more than 90 % [4]. Acceleration voltage of electron can be realized from 0.6 to 2.5 [kV] by gas-flow control. The constant power supply of current related to the emitted number of particles is controllable to a maximum of 40 [mA]. Beam emission angle is about 12 degrees.

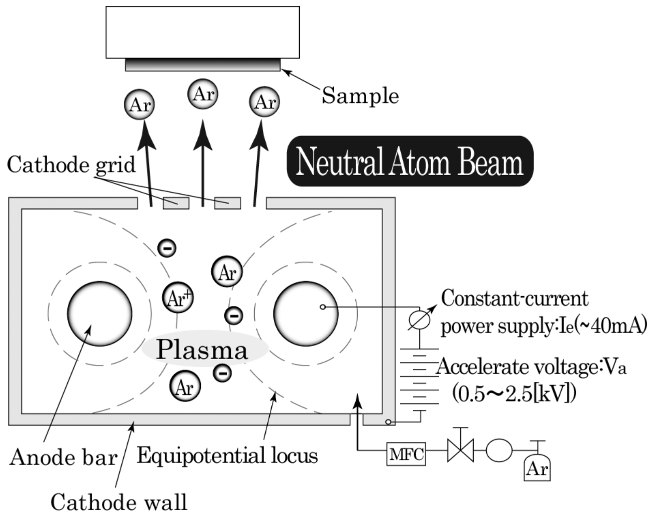

Fig.1 Configuration of the Fast Atom Beam (FAB) etching system.

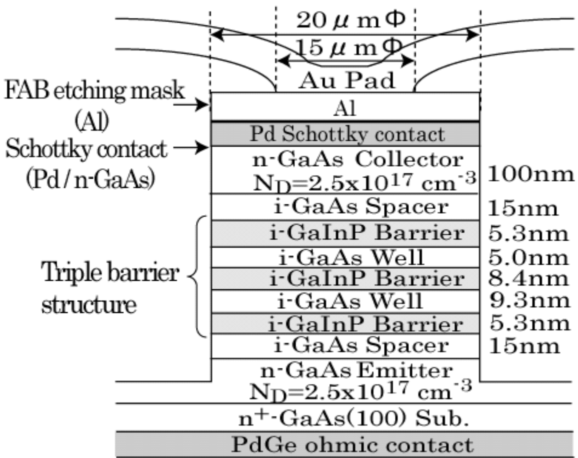

Fig.2 Schematic device structure of GaInP/GaAs Schottky collector TBRTDs fabricated by FAB process.

3. Experiments

A structure of fabricated GaInP/GaAs Schottky collector TBRTD schematically is shown in Fig.2. The FAB etching or wet etching process was used to define a mesa structure. The diameter of the mesa was 20 m. In the wet etching process, H_2SO_4:H_2O_2:H_2O =1:8:80 and H_3PO_4:HCl:H_2O =1:1:1 solution were used to etch GaAs and GaInP layer, respectively. Ohmic and Schottky contacts were formed by PdGe and Pd depositing on GaAs, respectively, by electron beam evaporator. Prior to the metallization, a sample was treated by ozone-cleaning and dipped in HCl:H_2O=1:1 solution to remove native oxide.

Concerning about the FAB etching, acceleration voltage was set to 1.5 [kV], and current supply was set to 30 [mA]. As FAB etching mask for GaAs, we used patterned Al. The etching rate of Al and GaAs were estimated 40 and 100 [nm/h], respectively as shown in Fig.3. The etching rates were constant during three hours, and extrapolation lines approach to the origin.

4. Results

Figure 4 shows the current-voltage (*I*-*V*) characteristics of GaInP/GaAs TBRTDs measured at 20 [K]. Ohmic collector and Schottky collector TBRTDs fabricated by FAB etching were indicated as oc-TBRTD-FAB and sc-TBRTD-FAB, respectively. Ohmic collector and Schottky collector TBRTDs fabricated by wet-chemical etching were denoted as oc-TBRTD-WET and sc-TBRTD-WET, respectively. NDRs with a large peak-to-valley (P/V) current ratio obtained in the TBRTD-FAB as compared with TBRTD-WET for both Scottky and Ohmic collector devices. Therefore, P/V ratios were improved from 1.2 to 2.8 for oc-TBRTDs and from 1.3 to 2.0 for sc-TBRTDs, respectively. Difference of measured peak-current between TBRTD-FAB and TBRTD-WET for both oc- and sc-samples comes from a fact that a difference of size definition of the collector top electrode as indicated insets in Fig.4 resulting difference of effective lateral size for vertical current path. The peak-current of sc-TBRTD-WET was slightly less than that of oc-TBRTD-WET because effective lateral size for the vertical current path is small in the sc-TBRTD-WET due to current concentration around the edge of metal electrode. Besides, the peak-current of oc-TBRTD-FAB and sc-TBRTD-FAB were almost identical since each top metal electrode was defined as same as the 20 m sized mesa diameter.

5. Conclusion

By using Fast Atom Beam (FAB) etching technology, GaInP/GaAs TBRTDs were fabricated and characterized. Novel improvement for negative differential resistance with large peak to valley current ratio was carried out by using the FAB etching as compared with wet chemical etching process in mesa formation. It suggests that the FAB etching process is expected as damage-free dry etching techniques for ultra-fine patterning of semiconductor.

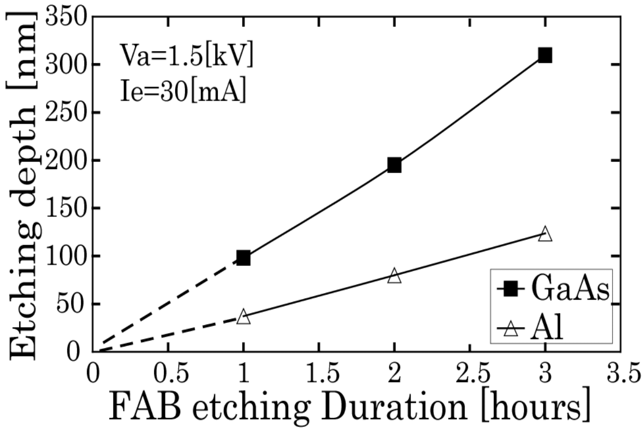

Fig.3 Relation between etching depth and etching duration in the FAB system. The etching rate of Al and GaAs were estimated about 40 and 100 [nm/h], respectively. The etching depth was measured by atomic force microscopy.

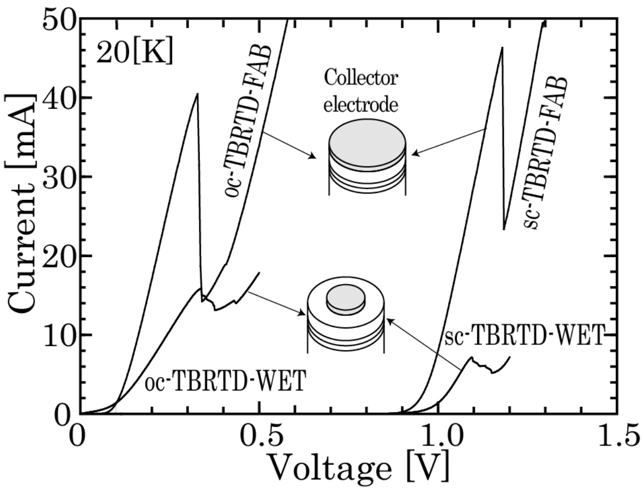

Fig.4 *I-V* characteristics of GaInP/GaAs TBRTDs measured at 20 [K]. Diameter of the mesa was 20 m for all samples. Ohmic collector and Schottky collector are indicated as oc- and sc-, respectively. TBRTDs fabricated by FAB etching and wet etching are indicated as TBRTD-FAB and TBRTD-WET, respectively. By using the FAB etching, NDR with a large P/V ratio was carried out. Schematics of top collector electrode are shown in insets.

6. Acknowledgment

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7. Reference

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