Plasma Processing Reactor on a Basis of Beam Plasma Discharge for Low Energy Etching of Heterostructures

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Abstract – The activity is directed on the solution of the task of creation of new type plasma processing low-pressure reactor for treatment of materials used in electronics engineering.

An effect, detected earlier by the authors, of generation of ion flow in beam plasma discharge (BPD) at low magnetic field underlies of the offered technology. This flow propagates to periphery of area of the discharge with energies in range 20–100 eV. The approbation of the technology of soft etching by ion flows from BPD in the Ar treatment of AlGaAs barrier layer of semiconducting AlGaAs/InGaAs/GaAs heterostructure, used for manufacturing of pseudomorphic high-electron mobility transistors (p-HEMT), is carried out. The influence of such processing on concentration and mobility of electrons, sensing to radiation defects imported during etching, was researched. The presence of effect of etching without an essential degradation of parameters of heterostructures (mobility of electrons) is shown, that testifies to small density of radiation disturbance.

1. Introduction

Now at production of a broad spectrum of semiconductor devices, from lasers up to microcircuits of microwave band on the basis of silicon and semiconducting compounds AIII/BV, are widely used different plasma assisted chemical processes as for etching and cleaning of a surface of semiconductors, dielectrics and metals, and their deposition on a surface of semiconducting structures. For these purposes mainly discharges of two configurations are used: a HF and UHF: discharge of an E-type (capacitive) between two flat electrodes (RIE technology) and discharge of a H-type (inductive), generated inside a tuned-circuit coil of the generator (ICP technology). The activities on creation of plasma for plasma processing reactor by collision ionization of gas by electron beam of small density are known also [1].

One of the most important problems is the control of the power characteristics of ions bombarding a processed material, that is rather important for optimization of quality of processing. At ion etching of materials a cumulative distribution function of ions on energies and angular distribution of ions reaching a material surface, influence critically to rate and level of an anisotropy of etching, quantity of imported radiation defects. The control of a spatial distribution of bombarding particles in such discharges is important for an ion-beam deposition of films with rather homogeneous structure. The control of the shape of ion distribution function leads to selectivity of physical and chemical processes on a surface of a material, that is especially important in the applications, bound with modification of a surface.

Need for the equipment, which is capable to make "soft" defect-free etching of an open surface semiconducting heterostructure, compounds AlGaAs/InGaAs/GaAs and InAlAs/InGaAs/InP and selective etching (for example, gate groove of field-effect transistors) directly ahead of an ion-beam deposition of metals has been discovered clearly. Especially acutely problem of defect-free etching stands at manufacturing of devices on the basis of the latest and most perspective semiconducting compounds AlGaN/GaN, as the liquid processes in this case are inapplicable in general, and the defects generated at high energy etching are fatal to these structures.

2. Physical basis

In our researches [2] the effect of formation of ion flow in beam plasma discharge (BPD) at low magnetic field is detected. The flow propagates from a discharge axis on normal to periphery. BPD is generated by an electron beam with energy ~2 keV and current density 0,1–1 A/cm^2 in gas medium of low pressure (0,01–0,1 Pa) at low magnetic field (0.2–0.5 mT). At these conditions electrons of both beam and plasma are magnetized (their Larmour radius is much less than the transversal sizes of the chamber of interaction, while for plasma ions magnetic field is practically imperceptible.

The mechanism of generation of an ion flow is not researched entirely, but the outcomes of computer and physical experiments result in a conclusion, that the ions are accelerated by a potential gradient formed on boundary between area of discharge, occupied by the beam, and surrounding area of plasma. In paraxial area the highly non-equilibrium plasma with mean energy of electrons reaching hundreds electron-volts is created as a result of non-linear de-

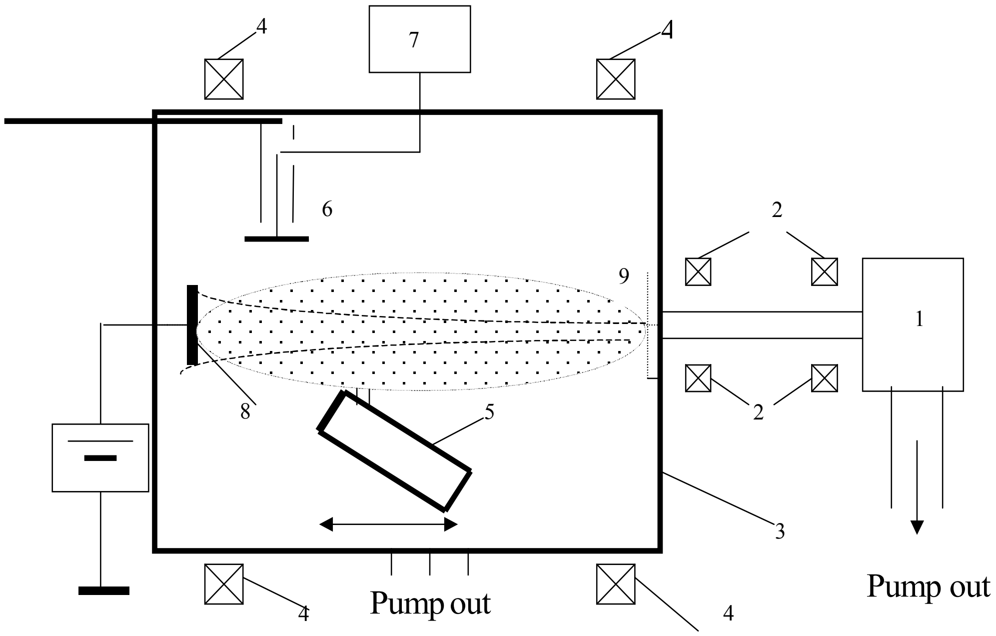

Fig. 1. An installation diagram. 1 – injector of electrons, 2 – focusing coils, 3 – evacuated chamber, 4 – Helmholtz coils, 5 – analyzer of energy of ions, 6 – header of a sample, 7 – sensor of ion current to a substrate, 8 – collector of discharge, 9 – UHF modulator of a beam

velopment of beam instability. The departure of high-energy electrons from this area leads to its higher positive potential in comparison with periphery of discharge.

The potential of paraxial area can be controlled, changing a spectrum of excited oscillations or changing a potential of a collector of discharge. Effect on a flow of electrons along an axis thus is implemented. It is shown experimentally, that on the basis of BPD the source of a flow of ions with energy adjustable in an interval 20–100 eV with a current density up to 1 mA/cm^2 can be created.

The scheme of a prototype installation is shown in a Fig. 1.

The plasma is formed in an evacuated chamber – cylinder of diameter $2R_0$=0,5 m and same length. Helmholtz coils form the longitudinal magnetic field with induction up to 0.5 mT in the chamber. The source of an axial beam is a diode gun of Pierce type with flat cathode of LaB_6 placed at the separate chamber, which incorporates with the main chamber by a handset of a pressure differential. Parameters of the beam on an input in the plasma chamber: accelerating voltage U_b=1–3 kV, current I_b – up to 500 mA, reference diameter 1÷1,5 cm. A power supply of the gun provides its pulsed operation with pulse duration τ_b=10–200 ms.

At an opposite wall of the plasma chamber the collector of electrons is placed.

As the receiver of an ion flow the electrostatic analyzer with a flat rejecting mirror movable along an axis at a lateral wall of the plasma chamber is used. The collimator of ions is oriented perpendicularly axis of the chamber. Parameters of an analyzer are: range of energies – 0–100 eV, sensitivity ~$0,5\cdot10^{-9}$ A/cm^2, energy resolution – $\Delta W/W_0$=0,12.

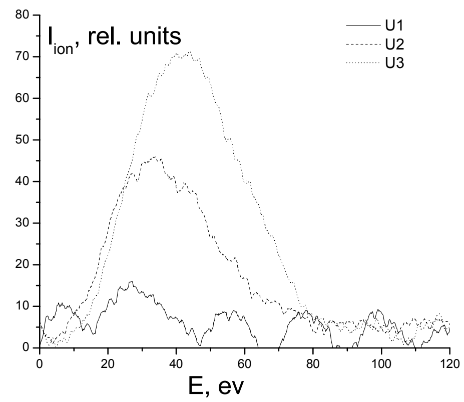

Fig. 2

In a Fig. 2 typical curves of cumulative distribution function of an ion flow on energies registered at different voltages on a collector of discharge are shown.

3. Approbation

The approbation of the technology of soft etching by ion flows of Ar^+ with mean energy 60–70 eV of pseudomorphic semiconducting heterostructures AlGaAs/InGaAs/GaAs (P-HEMT) with two-dimensional electron gas (2DEG), brought up on substrates of GaAs and applied for manufacturing of microwave field effect transistors has been carried out. The influence of such processing to concentration and mobility of electrons 2DEG, sensing to radiation defects imported during etching was researched.

The holder of a substrate is made from Teflon with heat sensor and auxiliary flat probe – sensor of a current of ions. A collector of discharge is molybdenum disc of 8 cm in diameter. After chemical cleaning of the chamber the sample (segments of plates with heterostructures or plates of diameter 60 mm wholly) was established on a substrate holder and the pumping out of an evacuated chamber up to pressure 2 mPa implemented. After filling with working gas additional cleaning of the chamber by ion bombardment and etching of a sample during fixed time with the control of parameters of discharge and current of ions on the auxiliary probe were conducted. Reference time of processing was 6 hours at a duty cycle of pulses of the electron injector 10. Conditions of etching were: pressure of gas – 0.1–0.2 Pa, mean energy of ions – 70 eV.

The researches that have been carried out on test samples p-HEMT of structures with Hall contacts have shown, that at conditions mentioned above there is no accumulation of radiation defects aggravating parameters of two-dimensional electron gas.

The version of technological process of manufacturing gate grooves of p-HEMT devices through a slot in dielectric is tested also. With the help of an electron beam lithography narrow (0.1–0.5 microns) slots in resist were made, through which the selective etching of dielectric coating Si_3N_4 by width 80 nm up to a layer of the semiconductor GaAs, where the process of etching stopped, was made. After resist removal the sizes of etched grooves were measured with the help of an atomic microscope. The depth of etching at the designated above time of exposure has made 35 nm. There are no detected signs of a non-uniformity of etching on a plate of 60 mm diameter. The presence of effect of etching without an essential degradation of parameters of heterostructures (mobility of electrons 2DEG) testifies to small density of radiation disturbance and possibility of using BPD in the technology of manufacturing of heterostructure microwave HEMT devices.

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