Reactive Ion Beam Etching (RIBE) of Compound Semiconductors

Etching of compound semiconductors for photonic devices

Anisotropic dry etching of III-V and II-VI compound semiconductors is widely used for patterning and production of gratings for optoelectronic devices like laser diodes. The manufacturing of suitable surfaces for optical resonators resides on the cutting edge of optoelectronics processing, especially for generating surfaces oblique to crystal planes and therefore not achievable by cleavage.

Reactive ion beam etching (RIBE) is commonly the method of choice for producing structures and interfaces with an arbitrary orientation with respect to crystal orientation and/or sample surface. Beside of the independence of structural orientation, RIBE also allows an easy and continuously variable orientation of the generated structures.

All process results shown in this document were performed on an IonSys 500 system which was fitted with a single sample load-lock system. The system layout is based on a handling concept with a standard size sample carrier. The carrier allows flexible mounting and processing of sample sizes between 10 mm and 150 mm.

The chuck for processing the sample/carrier combination is fitted with a thermo-liquid based cooling or heating capability -20°C to 100°C which couples to the sample carrier via a Helium gas backside contact. Additionally the wafer stage is fitted with continuous rotation with up to 20 rpm and tilting capability between 0 and 90° with respect to the ion beam. Sources as well as other system components have unlimited compatibility to chlorine and fluorine based gas chemistry.

Different process steps can be performed in one run by automatic control of recipe sequences. Altogether this makes the IonSys 500 the ideal platform small scale production and research and development for optics and semiconductor production.

Reactive ion beam etching process for III-V semiconductors

One well established and highly developed ion beam etching technique is reactive ion beam process (RIBE). In RIBE a chemically reactive gaseous species is fed into an ion beam source which can be either microwave (ECR - Electron cyclotron resonance) or radio frequency (ICP - Inductively coupled plasma) driven. The process gas molecules are dissociated and/or ionized in the source by the energy of the applied microwave or RF fields.1 Highly reactive species are then extracted from the plasma by a multi-aperture grid system, accelerated to a defined energy and directed to the sample surface. For tuning physical versus chemical etch regime a noble gas can be mixed with the reactive gas.

A suitable RIBE process for III-V semiconductors uses chlorine as a chemically active species with a certain argon addition. An addition of BCl3 is used to improve the anisotropy further by producing a passivation film on the sample substrate. This passivation film gets easily removed by the ion beam on horizontal surfaces but remains and passivates sidewalls by preventing direct chemical attack at these positions.2

Fig.1: View of a facet with well defined 45° sidewall angle etched on an IonSys 500 by RIBE into a stack of compound semiconductors for photonics applications
Sidewall angle control

Because of the directed ion flux, ion beam etching is a versatile tool controlling structural orientation especially side wall angles of processed structures. However, multiple parameters have influence on these geometrical effects:

- Ion incident angle: This angle is mainly fixed by the tilt angle of the wafer stage. However, one should always have in mind that any ion beam has always a certain divergence.
- Wafer orientation / rotation: Structural effects are influenced by continuous wafer rotation or by defined static orientation of the wafer with respect to the beam.
- Contribution of reactive and sputter erosion: This ratio defines the amount of spontaneous etching of the reactive species compared to the directed kinetically drive sputter erosion. As the two major factors this ration is influenced by the mixture of reactive and inert gases and by the ion energy.
- Mask stability: The sidewalls of the mask erode during the sputter process and as a result the edge of the mask migrates continuously as the etch process proceeds finally generating a sidewall in the etched struc-ture with a positive slope. However, the steeper the sidewall angle of the mask and the higher the selectivity of the process, the better the etch results will be in terms of sidewall quality. Suitable mask materials for patterning of compound semiconductors by RIBE are silicon dioxide and silicon nitride, which allow excellent selectivity for high aspect ratio. Photoresist, preferably hard-baked, is also utilized for RIBE pro-cessing.

The superposition of these effects tends to prevent a tilt angle from being exactly transferred into a sidewall angle. Each process therefore needs an individual angle calibration. Moreover, the microscopic quality of the sidewall surface is further influenced by the applied parameter set. As an example Fig. 1 shows a 45 ° sidewall in an etch structure which was achieved with static wafer orientation, Fig. 2 shows a perpendicular structure achieved with continuous wafer rotation and non-perpendicular ion incidence.

Etching of GaAs

In the case of gallium arsenide samples AsCl₃ and GaCl₃ are formed as the etch products. While GaCl₃ is volatile and evaporates easily at room temperature, AsCl₃ needs to be desorbed at slightly increased sample temperature of about 80 to 100 °C. Without increased temperature the process tends to be limited by the AsCl₃ desorption. For most of applications etch rates of about 200 nm/min are achieved at ion energies at or below 500 eV. With SiO₂ masks a selectivity of 10:1 is easily exceeded. As shown in Fig. 1 at optimized parameter settings very straight and defined sidewalls or facets can be achieved with negligible sidewall re-deposition or slope variation.

Etching of AlGaAs and AlGaNp

Other compound semiconductors like AlGaAs, InGaAsP or AlGaNp are etched by Cl₂ / BCl₃ / Ar admixture. As in the case of gallium arsenide reaction products like InCl₃ and AlCl₃ are of low volatility and need to get evaporated by increased sample temperature. Favorable substrate temperatures for the process on AlGaNp are above 100°C.

Dependent on the parameter settings and the material etch rates vary in the range of 150 to 350 nm/min. For the perpendicular etch structure in Fig. 2 an ion incident angle of 80 ° was adjusted. The selectivity using SiO₂ masks ranges in between 1:5 to 1:10.

References

3 Franz Eberhard, InGaAs/AlGaAs Laserdioden mit trockengeätzten Resonatorspiegeln, Cuvillier Verlag

Fig.2: 1.3 µm high structure with steep sidewall angle etched on an IonSys 500 in AlGaNp using a 300 nm Si₃N₄ mask