Proceedings of the XXV International School of Semiconducting Compounds, Jaszowiec 1996

MATERIALS TECHNOLOGY FOR GaSb-BASED OPTOELECTRONIC DEVICES*

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A study is made of surface preparation, metallization, patterning and dielectric deposition with the aim of developing process technology for GaSb-based photonic devices.

PACS numbers: 73.40.Ns, 81.05.Ea, 81.40.-z

1. Introduction

Semiconducting antimonide compounds have received increasing attention as the alternative materials for midinfrared photonic devices, with a variety of applications such as remote sensing, pollution monitoring, and molecular spectroscopy [1]. In this paper we present the results of our recent work towards the development of a fabrication technology for GaSb-based devices. Specifically, we have conducted a study of etchants, metal contacts, and dielectrics for application to light emitting diodes (LEDs) and double-channel mesa-structure laser diodes (LDs).

Our work was conducted on commercially available (100) oriented GaSb monocrystalline substrates, both p-type and n-type, with doping level of $1 \div 5 \times 10^{18}$ cm^{-3} and 1×10^{17} cm^{-3} respectively, and GaSb/$Al_xGa_{1-x}As_ySb_{1-y}$ ($x = 0.20 \div 0.5$, $y = 0.03$) structures grown by liquid phase epitaxy. Substrates were initially chemo-mechanically polished with bromine in ethylene glycol (1 : 8) solution.

2. Etching studies

We have investigated etching processes as a means for well-controlled treatment of the surface before deposition of metallic and dielectric layers, as well as for patterning of mesa structures. The effects of various etches on GaSb-based materials were studied with special attention paid to surface quality, etching rate and etching profile. Etches studied included aqueous solutions of HF, HCl and NH_4OH, which were proved to be effective in removal of native oxides from GaAs, various combinations of Br_2–HNO_3–HCl–CH_3COOH, and HCl–H_2O_2–H_2O. From among the solutions we examined, HF, HCl and NH_4OH-based solutions had very low etching rates (about 10 nm/min) and the surface remained smooth and featureless.

*The present work has received a financial support from the European Community Copernicus Project no. CIPA-CT94-0158.

$HCl–H_2O_2–H_2O$ (60+1+1) gave good results for the surface quality, and a reasonable etch rate of 4.4 μm/min for GaSb and 3 μm/min for $Al_xGa_{1-x}As_ySb_{1-y}$.

Taking into account the LD structure, we were interested in etching through p-GaSb(0.5 μm)/p-GaAlAsSb(2.5 μm) epitaxial layers to form a double-channel mesa structure in n-$GaSb_{substr}$/n-GaAlAsSb/n-GaInAsSb/p-GaAlAsSb/p-GaSb heterostructure. Etching studies included both wet and dry reactive ion etching (RIE) processes. Etching tests were conducted by forming an appropriate etch mask on the surface of the sample. The mask was examined prior to removal for any degradation, and an etch depth was measured afterwards by means of an alpha-step stylus profilometer and scanning electron microscope. Of all the etches studied, $HCl–H_2O_2–H_2O$ (60+1+1) solution was found the most suitable for patterning purposes. This solution does not erode the photoresist. Figure 1a shows a feature etched into GaSb/$Al_xGa_{1-x}As_ySb_{1-y}$ structure using wet etching. Let us note that the overetching is 3 μm/side.

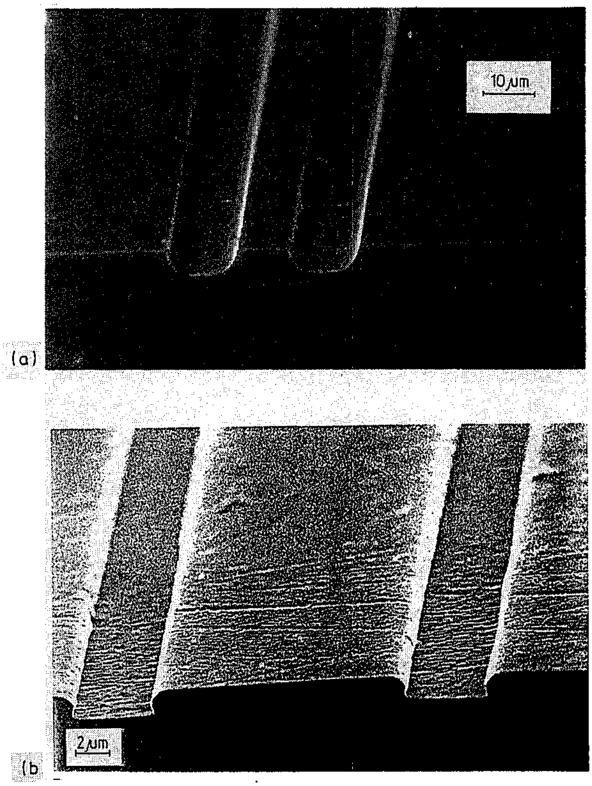

Fig. 1. Double channel mesa structure in $Al_xGa_{1-x}As_ySb_{1-y}$/GaSb (the etch mask consisted of 16 μm wide mesas and 4 μm wide channels): (a) wet etching in $HCl+H_2O_2+H_2O$. Channel depth 5 μm, mesa width 10 μm; (b) reactive ion etching in CCl_4/H_2. Channel depth 2 μm, mesa width 16 μm.

Reactive ion etchings were performed in a diode configuration RIE chamber with a 13.56 MHz power supply, using CCl_2F_2/H_2 and CCl_4/H_2 process gases. The optimum etch conditions providing vertical side walls and residue free etch surfaces, at considerable etch rates were obtained with CCl_4/H_2 plasma at a pressure of 150 μbar, rf applied power of 30 W, and gas flow rate 7/12. The etch rate was 200 nm/min. Since the etching agent damages the photoresist mask, RIE experiments were carried out using a SiO_2/Cr double layer mask. In Fig. 1b an example of a double channel mesa structure formed by RIE in $GaSb/Al_xGa_{1-x}As_ySb_{1-y}$ is presented. Note, resulting vertical side walls profiles.

3. Metal contacts

We have examined Ag-based, Au-based and refractory metal-based metallizations. Metal contacts were patterned by lift-off lithography. After metallization contacts were annealed at $100 \div 400°C$ for 3 min in hydrogen.

Ag-based metallization was deposited by sputtering in Ar atmosphere. We have used Ag–Mn(4%), Ag–Cd(2%), Ag–Si(4%) targets for contacts to p-type substrates, and Ag–Te(1.5%) and Ag–Se(1.5%) for n-type GaSb.

Au-based metallization was deposited by thermal evaporation of source materials in a vacuum of 2×10^{-6} torr. Contact layers, which we examined, included Au, AuZn and AuSb for p-type, and AuGeNi and AuSb for n-type.

Pure Pt and Pt with the Cr-adhesion layer were deposited by DC magnetron sputtering in Ar atmosphere. TiN metallization with the Ti-adhesion film was deposited by RF reactive magnetron sputtering from the Ti target in Ar/N_2(30%) atmosphere.

For p-type material all contacts studied gave linear I–V characteristics but Au-based contacts had the lowest resistances of approximately $1 \times 10^{-5}\ \Omega\ cm^2$. For n-type materials, contact resistances were uniformly higher with the resistance of *ca.* $5 \times 10^{-4}\ \Omega cm^2$. They gave good adhesion for lift-off lithography and bonding.

4. Dielectrics

Five types of dielectric films were investigated: SiO_2, Si_3N_4, SiO_2/Si_3N_4 sandwich structure, Al_2O_3 and TiO_2, deposited by RF magnetron sputtering in Ar. After deposition of dielectric films, 200 nm thick Au metallization, was deposited and patterned for electrical measurements (circular dots with diameter of 180,

TABLE

Electrical properties of dielectric films.

Dielectric	Current at 10 V	Local breakdown voltage	Breakdown voltage
SiO_2	10–100 pA	30–35 V	100 V
Si_3N_4	20–100 μA	–	–
SiO_2/Si_3N_4	30–100 pA	30–40 V	70 V
Al_2O_3	1–500 pA	20 V	80-90 V
TiO_2	> 1 mA	–	–

250, 350, 500, 700, and 1000 μm). The electrical characterization involved I–V measurements for voltages up to 100 V, for forward and reverse bias conditions. The results of breakdown voltage measurements are given in Table.

At the present stage of investigations we can state that SiO_2 dielectric films exhibit the best electrical performance.

The results of these investigations have been applied to fabricate LEDs and LDs operating at $\lambda = 2.0 \div 2.3$ μm at RT.

Acknowledgments

We would like kindly acknowledge Drs. M. Sawicki and J. Wróbel from the Institute of Physics, PAS, for making SEM pictures shown in this article.

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