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MASKLESS MICRO ETCHING OF GaAs DIRECTLY CONTROLLED BY CALCULATOR

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Abstract - Controlled etching of III-V compound semiconductors is an important step for the fabrication of discrete and integrated components. For this we developed a system which permits to obtain a 1 micron diameter light spot. Displacement of the spot on the sample and speed are controlled by a computer for any desired figure. The light spot is used to etch photochemically GaAs immersed in aqueous solutions.

Controlled etching of III-V compounds is an important step for the fabrication of integrated components. Several papers describe the use of a laser to etch photochemically GaAs in aqueous solutions. In the present paper we present the results we obtained with an apparatus we specially developped for these technics. We tried to get the best precision and reproductibility of the etched figures.

I - LIGHT BEAM SCANNING APPARATUS

The light is issued from a 632 nm He Ne laser. First the laser beam is focused in order to inject the light in a monomode optical fiber. Thus a spot of gaussian distribution of about 20 μm diameter is obtained at the other end of the fiber. Microscop optics then reduce the beam to a dimension of about 1.3 μm diameter. The optical path of a commercial microscope is used, allowing to illuminate the sample with an external white light so as to observe the sample and the spot, at the same time, through the binocular. The laser beam intensity can be gradually decreased, using a set of neutral optical densities, over 4 order of magnitude. The incident power sampled from a fraction of the beam is continuously measured with a photodiode.

The sample can be moved in two perpendicular directions by two step by step motors. The minimum step displacement is of 0.1 μm and the displacement precision of 0.1 μm. These displacements are controlled by a computer which permits to perform any desired figure at any speed allowed by the step by step motors.

The incident beam maximum power on the sample is 0.2 mW. Thus no thermal effect take place in the experiments we present (ΔT<3°C).

II - PREPARATION OF THE SAMPLES

We use aqueous solutions as an etching medium. The sample is covered by a small quantity of aqueous solution spread in a thin film by capilarity under a cover glass. Illumination is performed through the cover glass and the aqueous solution film.
We first started our experiments with aqueous solutions already mentioned in the literature to be active in similar experiments (Ref. 1 - 3). They are:

- KOH + H2O with dilutions of 1% and 5%
- HCl + H2O at 1%
- H2SO4 + H2O2 + H2O respectively 10cc, 13cc, 250cc.

III - EXPERIMENTAL RESULTS

The etching capabilities of the solutions and the apparatus have been studied using a displacement test drawing composed of lines of 100 μm length separated by steps of 4 μm, and this for a set of displacement speeds (picture 1). The displacement speeds are in the range of 1 μm/s to 9 μm/s. The etching speed is proportional to the light intensity. We obtained very close results for the different solutions tried. On the other hand, the etching speed is highly correlated to the material type of the sample. We can typically summarize our results by saying we use a beam intensity of 0.5 mW for n type GaAs and 0.2 mW for semi-insulating material in order to have the same etching speed. Concerning p type GaAs, we did not succeed to etch it by this method. The differences we obtain for the three solutions we use are due to their activity on illuminated GaAs. The solutions of HCl and H2SO4 are known to etch unilluminated material at room temperature even for the high dilutions we use to minimize this effect. The KOH solutions do not act on GaAs without illumination which is far more easy to put to work. Moreover, KOH do not damage AuGe ohmic contact which is not the case for acid solutions. The best surface aspect of the grooves are obtained for KOH solutions. The acid solutions often produce a granular aspect of the whole surface of the sample. An other major point is the preparation delay of the solution which may lead to solution quality degradation. We observed crystalline deposits on samples when using aged solutions.

Picture 1 shows the grooves obtained with KOH on a 10⁻⁸ cm⁻³ - 3 n type GaAs sample for three scanning speeds. The picture 2 presents a detail of the grooves shape and permit to see the quality of the surface after etching with KOH.

Picture 3 is a view of the etching obtained by a combination of successive drawings on a 10⁻⁸ cm⁻³ - 3 n type sample with KOH solution. First was performed a large groove of 10 μm width and 5 μm depth. Then the sample was scanned into a perpendicular direction in order to make thin grooves of about 1 μm width for different scanning speeds. All the operations have been performed in a same experiment, the control of the whole operation being achieved by the computer. We remark a hole of some microns depth at the top of the picture which correspond to the initial spot position before scanning started.

In order to show the resolution capabilities of the method we performed several optical gratings of 1250 grooves per millimeter (steps of 0.8 μm). We have chosen to present on picture 4 a view of a grating performed with HCl solution. The purpose was to obtain regular grooves of small depth. We have also chosen this figure to show the surface granular defects observed when using HCl. Gratings performed with KOH have a better surface aspect.

IV - INTERPRETATION OF THE RESULTS

We tried other experiments on samples on which AuGe ohmic contacts had already been evaporated. The KOH solution has no effect on AuGe, so that only uncovered material can be etched. Scanning the spot on AuGe do not produce any damage. Close to the contact edge, there is no etching and the etching rate decreases as the distance to the contact decreases. This must be related to the phenomena involved in the etching process.

The process is based on an electrochemical effect. For this we have to consider GaAs to have a natural surface depletion layer which lead to a surface electric field. This depletion layer is induced by surface charges which may be due to many external factors: oxides, solutions, etc... As etching goes on over microns we have to admit that after the etching has started, surface states due to external factors have been...
removed and are no longer the origin of the surface electric field. On the other hand we must notice that the pH of the solution has no predominant effect. We conclude that the surface charges are directly correlated to the surface defect itself (broken atomic bindings ?). Anyway it is admitted the Fermi level to be close to the midgap at surface of a type GaAs. So that the process can be described as:

- Creation of electron-hole pairs in the material by light absorption.
- Separation of the electron-hole pairs by the surface electric field.
- Accumulation of holes at the surface which permits to active the ion exchanges with the aqueous solution in an electrochemical process.

In such a photovoltaic effect we have to consider the diffusion of the minority free carriers in the material, related to the diffusion length and the high of the surface barrier. This explains the fact that near an ohmic contact, as the high of the barrier decreases, the etching capabilities decreases.

On the other hand for semi-insulating material the Fermi level is already close to the midgap, so that if a surface space charge region exists it must be very small. In such a case the process is mainly activated by the free carriers diffusion current rather than by a surface electric field induced current. This would be consistent with the difference in etching speed observed for semi-insulating material compared to n type material.

For p type material, a surface space charge region would lead to an accumulation of electrons at the surface. Noone succeeded in etching p type material by this process. We conclude that the activation of the electrochemical need an accumulation of holes on the surface of the semiconductor.

To summarize: for a given incident light power the etching rate depends upon the capability of the material to separate electron-hole pairs before recombination and to drive holes, to the surface of the crystal. The precision of the etching around the light spot depends of the diffusion length of the holes.

V - CONCLUSION

We developed a system which permits to execute most of the etchings for planar technology on GaAs without masks. The scanning speed and the light power can be controlled by the computer for any programmed figure. In particular, as etching rates ratio of n type and semi-insulating is in the order of 10, there is no difficulty to stop etching of an active n layer to its interface with a semi-insulating substrate (or p type underlaying material). We showed that aqueous solutions can be used which present no action on GaAs without illumination and moreover no damage for GeAu ohmic contacts.
The method studied with GaAs material should be extrapolated to III-V compounds. The best aqueous solution has certainly not yet been found as we have to investigate solutions that are normally inactive for III-V compounds.

Moreover there is no limitation to aqueous mediums, gas can be used as well without complication of the method.

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