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# Investigation of methods for texturing light-emitting diodes based on AlGaAs/GaAs heterostructures

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Investigations of methods for texturing the light-emitting surface of IR light-emitting diodes (LEDs) (wavelength 850 nm) based on AlGaAs/GaAs heterostructures with Bragg reflectors have been carried out. Developed were methods of liquid and plasma-chemical etching of solid solution for creating peaks (pyramids) of different form, $0.2-1.5\,\mu$m height. Estimation of the effect of texturing methods and also configuration of peaks on the light-emitting diode electroluminescence intensity has been performed. The increase of the electroluminescence intensity by 25% has been achieved.

**Keywords:** light-emitting diode, texturing, etching methods, electroluminescence.

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## 1. Introduction

The infrared (IR) light-emitting diodes with the radiation wavelength of 850 nm are used in various areas: in remote control panels, CCTV cameras, in security systems for IR backlight. The epitaxial growth technology of the AlGaAs/GaAs heterostructures are developed to achieve an internal quantum yield of the light-emitting diodes, which is close to 100%. However, the efficiency of output of radiation from the crystal is significantly lower due to high radiation reflection coefficients at the semiconductor-air heterointerface. One of the simplest and most widespread methods of increasing the efficiency of the radiation output is texturing a light outputting surface of the light-emitting diode using the technology of liquid chemical and plasma-chemical etching [1–3]. The microrelief can be formed either in a dielectric coating formed on the light outputting surface [4], or directly in the AlGaAs solid solution [5].

The present paper provides the results of studies of various texturing methods of the light outputting surface of the light-emitting diodes based on the AlGaAs/GaAs heterostructures. Methods of the plasma-chemical and liquid chemical etching of the $Al_{0.2}Ga_{0.8}As$ solid solution have been developed and optimized to form peaks (pyramids) of a various configuration.

Use of the methods of plasma-chemical etching of the light outputting surface is a labour-consuming and expensive method. It is etched via a mask of polystyrene spheres being formed on the heterostructure surface [6,7]. The spheres are uniformly distributed on the surface of the light-emitting diode when being transferred them from a water surface. Then a sphere diameter is optimized in the oxygen plasma and the AlGaAs solid solution is directly etched inside the $BCl_3$ plasma.

An alternative method of texturing the light-outputting surface of the light-emitting diodes is liquid chemical etching, which can be performed both using a photoresist mask and directly through a mask of front ohmic contact, thereby significantly facilitating the technological process.

## 2. AlGaAs/GaAs heterostructure

The investigations were carried out on the AlGaAs/GaAs heterostructures, which were grown by the MOCVD technique on the $n$-GaAs substrates (Fig. 1). The heterostructure started growing by forming reflectors based on a $n$-$Al_{0.9}Ga_{0.1}As$ (300 nm) wide-band layer and a Bragg reflector (BR) [8], composed of 15 pairs of the $n$-$Al_{0.9}Ga_{0.1}As$/$n$-$Al_{0.1}Ga_{0.9}As$ layers. The active region includes six InGaAs quantum wells provided between the wide-band emitters and the $Al_xGa_{1-x}As$ ($x = 0.2-0.4$) barrier layers of the $n$- and $p$-type. The heterostructure finished growing by crystallization of strongly alloyed $p^+$-$Al_{0.2}Ga_{0.8}As$ layers ($4-6\,\mu$m), which provide for a reduced spreading resistance of the front $p$-region of the heterostructure and the $p^+$-GaAs contact layer required to reduce the transition contact resistance of the front ohmic contact [9].

## 3. Post-growth technology of forming the light-emitting diode chips

The post-growth technology of forming the light-emitting diodes based on the AlGaAs/GaAs heterostructure includes several stages:

– creation of a bus-bar front ohmic contact of the $p$-type of conductivity;

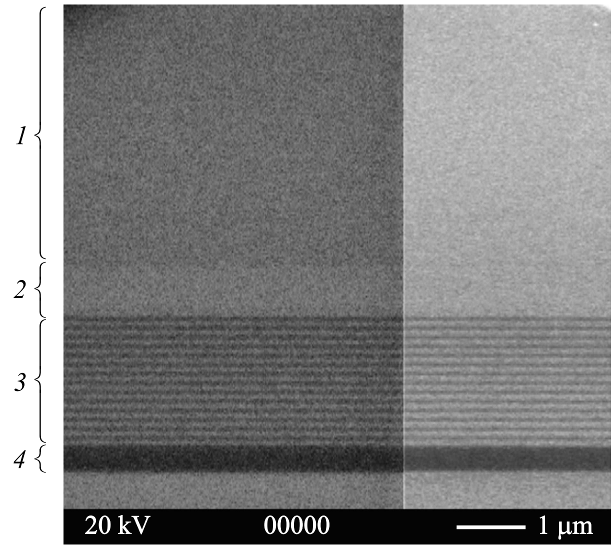

**Figure 1.** Image obtained by the scanning electron microscope (SEM), of a cleavage surface of the AlGaAs/GaAs heterostructure, where *1* — the $Al_{0.2}Ga_{0.8}As$ solid solution, *2* — the active region and the wide-band emitter, *3* — the BR, *4* — the $Al_{0.9}Ga_{0.1}As$ layer.

– formation of a solid rear ohmic contact of the *n*-type of conductivity;

– formation of a separating mesa-structure;

– texturing a light-outputting surface of the light-emitting diodes;

– deposition of an anti-reflecting coating.

The light-emitting diodes were textured by the mask of the bus-bar ohmic contact using the plasma-chemical and liquid chemical etching of the $Al_{0.2}Ga_{0.8}As$ solid solution in order to increase the efficiency of the radiation output.

The anti-reflecting coating, which is based on the $TiO_x/SiO_2$ layers and optimized for the radiation wavelength of 850 nm, is deposited to the light-radiative surface of the light-emitting diodes and the area of the separating mesa-structure. The anti-reflecting coating is formed on the light-radiative surface to provide for reduction of Fresnel reflection on the semiconductor-air interface. The $TiO_x/SiO_2$ dielectric layers are deposited to the separating mesa-structure to provide for its passivation and protection, thereby resulting in reduced leakage currents of the $p-n$-transition along a mesa's side surface. Furthermore, the anti-reflecting coating layers play a protective function when performing subsequent technological operations of bonding and packaging of the light emitting diodes.

## 4. Methods of texturing of the light-outputting surface of the heterostructures

The plasma-chemical method of texturing of the light-outputting surface of the light-emitting diodes is investigated. The mask of the bus-bar front contact was used to pre-etch the GaAs contact layer in places which have no contact, thereby uncovering an underlying layer of the $p^+$-$Al_{0.2}Ga_{0.8}As$ solid solution. The solid solution surface was made to form the mask of polystyrene spheres by transferring them from the surface of 40%-solution of ethyl alcohol, providing increase in surface wettability and uniformity of the sphere distribution.

The etching was performed on the STE ICP 200e plasma-chemical etching unit (SemiTEq). The polystyrene spheres were pre-formed in the oxygen plasma to give an optimal topology of the mask and obtain a required diameter of microspheres. The solid solution was textured in the boron trichloride plasma ($BCl_3$) due to its lesser toxicity and lesser chemical activity in comparison with clean chlorine. In comparison with the chlorocarbon compounds, $BCl_3$ has a less degree of polymerization in discharge conditions, which prevents contamination of the unit and the heterostructure during etching [10].

In order to form the peaks (pyramids) on the light-outputting surface of the light-emitting diode, the optimal modes of plasma-chemical etching of the $Al_{0.2}Ga_{0.8}As$ layer with the rate of $\sim 1-1.2\,\mu$m/min have been developed.The peak height on the light-outputting surface was $0.2-0.4\,\mu$m (Fig. 2), thereby providing for maximum increase in the electroluminescence at the wavelength of 850 nm [3,5].

There was investigation of the methods of liquid chemical etching in the etchants based on nitric acid of a various concentration, as well as based on hydrofluoric acid, ammonium fluoride and hydrogen peroxide. The texturing in the dilute nitric acid can be performed in a single technological cycle in one solution, both for etching the $p^+$-GaAs contact layer on the light-outputting surface of the light-emitting diode, and for etching the $p^+$-$Al_{0.2}Ga_{0.8}As$ solid solution to the depth of $2-3\,\mu$m to form texturing pyramids of the height of $1-2.5\,\mu$m (Fig. 3). However, when using nitric acid of the various concentration ($HNO_3$ 20–25%), the etching rate is very high, it is $0.5-0.7\,\mu$m/s, thereby resulting in reduction of a profile accuracy of the

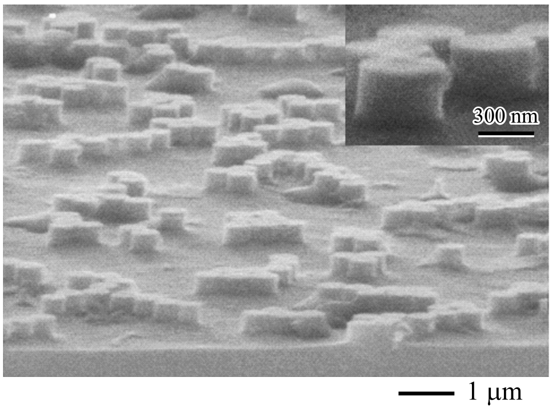

**Figure 2.** Picture of the SEM cleavage surface of the AlGaAs/GaAs heterostructure after surface texturing in the $BCl_3$ plasma.

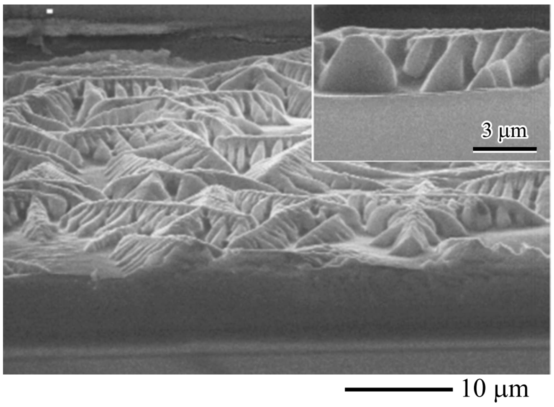

**Figure 3.** Image of the SEM cleavage surface of the AlGaAs/GaAs heterostructure after surface texturing in dilute nitric acid.

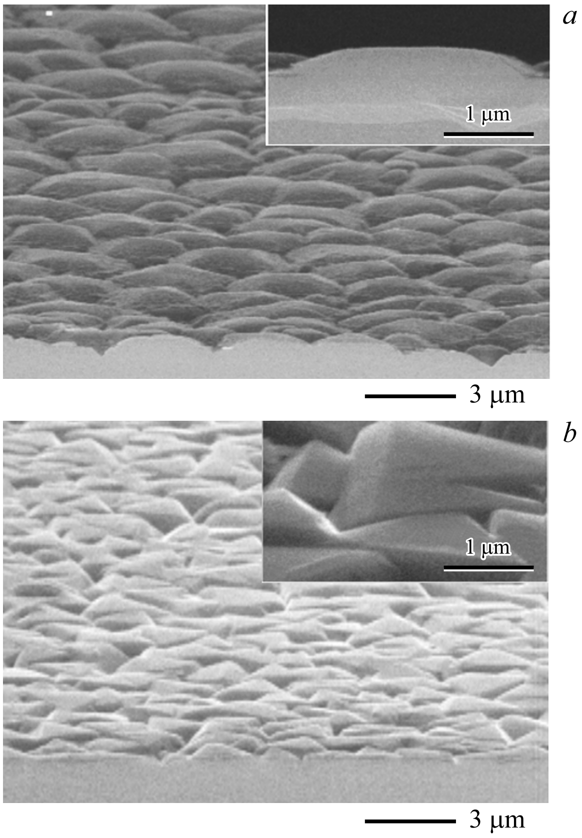

**Figure 4.** Image of the SEM cleavage surface of the AlGaAs/GaAs heterostructure after surface texturing in the $HF:NH_4F:H_2O_2$ etchant for 30 s (*a*) and 100 s (*b*).

textured surface. Even at a very short etching time of 2 s, the pyramid height exceeds $1\,\mu$m. The change of the $HNO_3$ concentration results in disbalance of an oxidizer and a reducer in the solution, thereby preventing normal proceeding of the chemical reactions and resulting in a reduced density of the peak location on the heterostructure surface.

There was then development and investigation of the etchant based on the hydrofluoric acid, ammonium fluoride and hydrogen peroxide ($HF:NH_4F:H_2O_2$ as rated by mass in $6:42:8$). This composition turned out to be an optimal one, but when using it there is selectivity of etching in relation to the $p^+$-GaAs contact layer. That is why it should be structured in two stages. The contact layer is pre-removed in the etchant based on hydrogen peroxide and ammonia in order, thereby uncovering the underlying layer of the $p^+$-$Al_{0.2}Ga_{0.8}As$ solid solution. The second stage includes etching the $HF:NH_4F:H_2O_2$ etchant for $15-100$ s.The first stage of texturing the solid solution (up to 30 s) includes evident formation of the semi-spheres of the height $0.2-0.5\,\mu$m (Fig. 4, *a*). When extending the processing time to $60-100$ s, there is smoothing of a front surface of the semi-spheres and formation of truncated pyramids with a base of $\sim 1-2\,\mu$m (Fig. 4, *b*). The rate of etching of $p^+$-$Al_{0.2}Ga_{0.8}As$ is $0.8-1.2\,\mu$m/min, thereby allowing controllable surface texturing with formation of the peaks of the various height $0.2-1\,\mu$m.

## 5. Characteristics of the light-emitting diodes

The influence of the structuring of the $Al_{0.2}Ga_{0.8}As$ solid solution on the parameters of the light-emitting diodes was analyzed by investigating the change of the current spreading resistance of the upper wide-band window and the electroluminescence intensity when etching the heterostructure surface by various methods. The spreading resistance affects the uniformity of distribution of the current passing through the $p-n$-transition. The electroluminescence intensity characterizes the crystal radiation output efficiency. The texturing of the light-emitting diode's surface results in the decrease in the upper wide-band window layer thickness and, consequently, to the increase in the radiation output efficiency, but it also provides for increase in the radiation output efficiency in multi-pass structures. If obtaining the optimal relationship of the minimum current spreading resistance and the maximum electroluminescence intensity of the light-emitting diodes, it provides for increase in the instrument operation efficiency.

The current spreading resistance was measured on test samples, which were fabricated as a square $1 \times 1$ mm with two strip contacts on the opposite sides at the distance of $600\,\mu$m from each other. The resistance was measured by an ohmmeter between the two front contacts of the test sample (see Table). The resistance value, thus measured, corresponds to a sum of a layer resistance and a resistance of the metal-semiconductor contact for both the contacts. As per TLM (Transmission Length Method) [11], the contact resistance is at most 0.1 Ohm, which is significantly lower than the layer one, and it can be neglected.

The radiation output efficiency of the light-emitting diode's crystal using a fiber-optic spectrometer with a converging (collimating) lens (it can capture a substantial

Spreading resistance of the test sample 1 × 1 mm

| Sample № | Texturing method | Etching depth, $\mu$m | Sheet resistance, Ohm · per square |
|---|---|---|---|
| 1 | No texturing | 0 | 30 |
| 2 | Etching in the $BCl_3$ plasma | 0.2–0.4 | 38 |
| 3 | Chemical etching in $HF:NH_4F:H_2O_2$ | 0.3–0.5 | 40 |
| 4 | Chemical etching in $HNO_3$ (25%) | 3 | 50 |

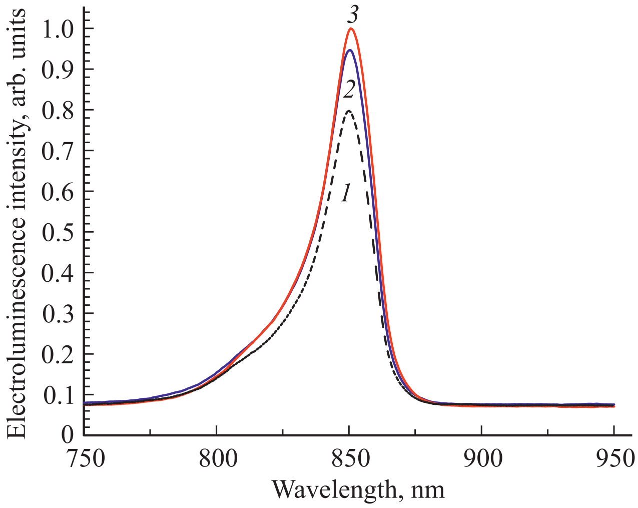

**Figure 5.** Influence of the methods of surface texturing of the AlGaAs/GaAs-light-emitting diodes on the electroluminescence intensity: *1* — no texturing, *2* — texturing in $BCl_3$ plasma, *3* — texturing in $HF:NH_4F:H_2O_2$ etchant.

part of the light-emitting diode radiation) was analyzed by comparing the electroluminescence at the wavelength of 850 nm for the crystals with various texturing methods at the same current passing through LED (Fig. 5). It allowed qualitatively comparing the radiation output efficiency of the crystals. Since the studied samples differed only in methods of processing of the light-outputting surface, the difference in the emission intensity allows qualitatively evaluating the influence of the microrelief shape on the radiation output efficiency of the light-emitting diode.

The texturing methods were analyzed by measuring the electroluminescence intensity for the light-emitting diodes without processing the light-outputting surface, with texturing in the $BCl_3$ plasma in an etchant based on dilute nitric acid and based on hydrofluoric acid, ammonium fluoride and hydrogen peroxide. The use of the etchant based on the dilute nitric acid for texturing the light-emitting surface results in substantial increase in the spreading resistance in more than 1.6 times and degradation of parameters of the light-emitting diodes with unsubstantial increase in the electroluminescence intensity. When texturing the light-emitting diode in the $BCl_3$ plasma, it is quite difficult to provide for uniform etching of the heterostructure surface. However, at the same time there is an increased intensity of electroluminescence by 20% at the peak height of 0.2 $\mu$m (Fig. 5, the curve *2*). The use of the etchant based on hydrofluoric acid, ammonium fluoride and hydrogen peroxide results in a small increase in the sheet resistance and allows forming pyramid peaks of the height of 0.2–0.5 $\mu$m of a various configuration. The maximum increase in the electroluminescence intensity by 25% is achieved by texturing in $HF:NH_4F:H_2O_2$ for 30 s (Fig. 5, the curve *3*).

## 6. Conclusion

The various methods of texturing the light-outputting surface of the AlGaAs/GaAs light-emitting diodes have been investigated and developed. The maximum increase in the electroluminescence intensity by 25% is achieved by the liquid chemical etching of the light-emitting surface of the heterostructures in $HF:NH_4F:H_2O_2$ at the etching depth of 0.2–0.5 $\mu$m. These investigations were carried out on the heterostructures with the Bragg reflector, which ensures effective reflection of radiation falling at angles near 90°. Fuller reflection of radiation is provided by producing the light-emitting diodes with a rear silver mirror. The effect by texturing of the light-outputting surface on these samples can substantially increase.

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### Conflict of interest

The authors declare that they have no conflict of interest.

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