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INFLUENCE OF FABRICATION PROCEDURE ON BASIC CHARACTERISTICS OF SEMICONDUCTOR LASERS

M. Kaniewska, J. Ratajczak

Institute of Electron Technology, al. Lotników 32/46, 02-668 Warszawa, Poland

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Abstract

Broad-area contact ridge waveguide technology has been used for manufacturing lasers from AlGaAs/InGaAs or AlGaAs/GaAs SCH-SQW or GRIN-SCH-SQW diode structures grown by MBE. The stripe-geometry ohmic contacts were made by sputtering Cr/Pt and defined by photolithography and metal lift-off. The ridge was formed during Ar-ion beam etching by removing the p$^+$-GaAs cap and part of the p-AlGaAs confinement layer besides the stripe. The P-I and I-V characteristics and light field intensity distributions were determined, and images from SEM were analysed for evaluation of the manufactured lasers. We report on the anomalies in laser characteristics if a metal layer covered the entire surface as usually in the lasers fabricated by means of this technique. Results presented are discussed in categories of effects influencing the electrical characteristics of the (Cr/Pt) – p-AlGaAs Schottky contact that formed outside the contact stripe. We conclude that defects in the vicinity of the metal – semiconductor interface, introduced during the processing steps, may be responsible for a poor rectifying behaviour of the Schottky contact. Consequently, a lack of the current spreading may be a reason of irregularities in characteristics of the laser studied.

1. Introduction

It is a well-known fact that the optical quality of laser diode structures grown by molecular beam epitaxy (MBE) as well as parameters of lasers made of the structures are strongly dependent on growth conditions. Growth runs at various substrate temperatures and flux ratios have to be performed to optimise growth conditions. Consequently, test structures grown under different conditions have to be tested in reality. For this purpose simplified procedures are then necessary that allow for quick manufacturing devices. In the ridge waveguide technology, in contrast to the previous technology of planar stripe geometry lasers, no complicated manufacturing processes are involved [1]. Moreover, a significant improvement in linearity of the light output-current (P-I) characteristics has been observed for (AlGa)As double heterostructure lasers prepared with the ridge waveguide technology [2].

In the present work, this simplified fabrication procedure has been used for manufacturing semiconductor lasers based on low-dimensional structures grown by MBE. Basic characteristics were measured and results of the measurements were analysed from point of view of the reliability of lasers fabricated by means of the ridge waveguide technology.

2. Experimental details

The laser diode structures used in this study were MBE grown AlGaAs/InGaAs separate-confinement heterostructure (SCH) or AlGaAs/GaAs graded-refractive index separate-confinement heterostructure (GRIN-SCH) with single quantum well (SQW) as the active region. The broad-area contact, ridge waveguide lasers were fabricated from the grown wafers and characterised. The stripe ohmic contacts of 50 μm or 100 μm widths, separated by 400 μm, were made by sputtering Cr/Pt on the top of the p$^+$-GaAs contact layer and then defined by photolithography and metal lift-off. The ridge was formed in the process of dry etching by means of the Ar-ion beam in which the p$^+$-GaAs contact layer and a part of the p-AlGaAs cladding layer were removed besides the stripe. The geometrical parameters, such as the stripe width and ridge height were controlled by means of the α-step surface profiler. The p-contact was alloyed at 490°C/3 min in H_2 atmosphere under a hermetic cover. After removing silicon oxide that was also used as the mask for etching, the Cr/Pt metallisation was deposited over the entire surface and subsequently annealed together with the Au-Ge-Ni n-contact at 410^{o}C/3 min. At the end, the contact metal was thickened in galvanisation process by deposition of Au that formed the so-called montage layer. For comparison, some lasers had no montage layer and some of these lasers had the one level of Cr/Pt metallisation restricted to the contact stripe width. According to the different metallisation procedures, the lasers divided into three groups and labelled I to III, respectively.

The light output-current (P-I) and current-voltage (I-V) curves were measured and images from scanning electron microscopy (SEM) were analysed for characterisation of the manufactured lasers. Far field patterns (FFPs) were measured to analyse the light field intensity distributions.

Additionally, the dry etching process was simulated in $Al_{0.3}Ga_{0.7}As$:Si ($2.5 \cdot 10^{16}$ cm^{-3}) thick epitaxial layers. After Schottky diode formation, deep level transient spectroscopy (DLTS) measurements were carried out to study the presence of deep-level defects induced by the process. Schottky diodes, as the reference samples, were fabricated on the $Al_{0.3}Ga_{0.7}As$:Si layers by *in-situ* MBE evaporating a thin layer of Al.

3. Experimental results and discussion

Typical P-I dependence for the first type lasers is illustrated in Fig. 1a. As seen in Fig. 1a, anomalies such as "kinks" and increased noise are clearly seen in the P-I curve. The key parameters determined from the characteristics are the threshold current, I_{th}, and the differential quantum efficiency, η_{ext}. The threshold current equals 300 mA as determined for a 500 µm long laser. It is in the range of high values comparing to the value of 60 mA reported in the literature [3]. The differential quantum efficiency of the lasers is low and shows anomalies with increasing injection current. The P-I characteristics measured with a laser of the second type is shown in Fig. 1b. The noise is reduced and no characteristic kinks are observed in characteristics of these lasers studied. The I_{th} increases up to of 500 – 1200 mA due to a higher cavity length (1000 µm) used in these lasers. It is interesting to notice that undesirable properties exhibit lasers, which had the contact metal thickened with Au. Since the investigated lasers originate from the same epitaxial wafer, the influence of other laser parameters, such as layer characteristics and material quality, on the P-I characteristics can be neglected. It has been long established in the case of conventional stripe geometry lasers that the transverse mode structure in the direction parallel to the junction plane (horizontal mode structure) is unstable and changes with the pump level and other laser parameters. This instability is a cause of undesirable properties those lasers exhibit. Let us note, the effects observed in the lasers studied are very similar to those reported previously and has not been expected since a significant improvement in linearity of the P-I dependence has been stated in the case of lasers obtained with the ridge waveguide technology. Owing to the lateral confinement and the built-in passive waveguiding the transverse mode structure is expected to stabilise, thereby nonlinearities are avoided. Moreover, the effects are surprising in the case of broad-area contact lasers.

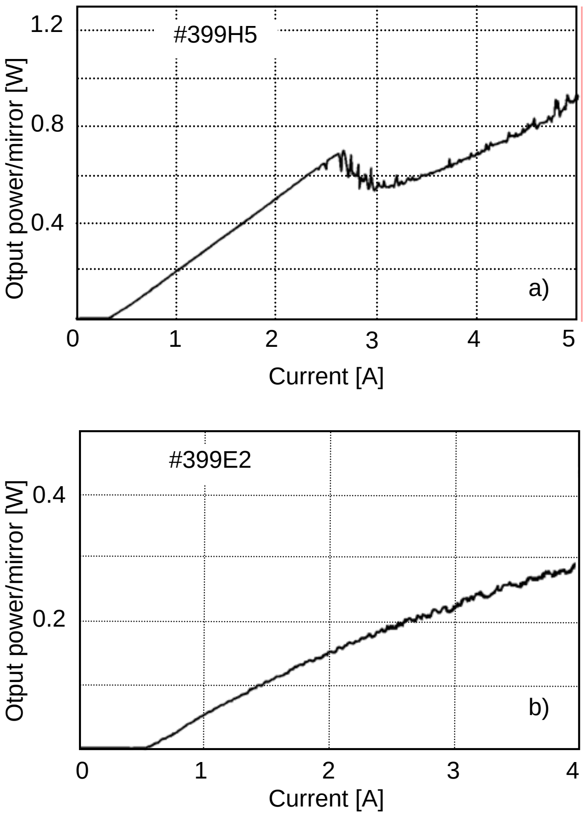

Fig. 1. Variation of optical power taken from one facet with current for AlGaAs/InGaAs SCH SQW lasers at room temperature under pulsed current conditions (200 ns pulse at 0.1 percent duty cycle): a) a 500 µm long laser of the type I (which had two level Cr/Pt metallisation and contact montage layer, b) a 1000 µm long laser of the type II (which had two level metallisation without contact montage layer).

Figure 2a and b present corresponding I-V characteristics of the lasers of the group I and II, which the P-I characteristics are shown in Fig. 1a and b, respectively. For comparison, results for a laser of the group III, in which metallisation was restricted only to the contact stripe, are shown in Fig. 2c. The latter exhibits a good rectification consistent with known properties of the p-n junction.

Generally, it is assumed that current flow in the lasers of the groups I and II is restricted to the area below the stripe where metal alloy makes a good

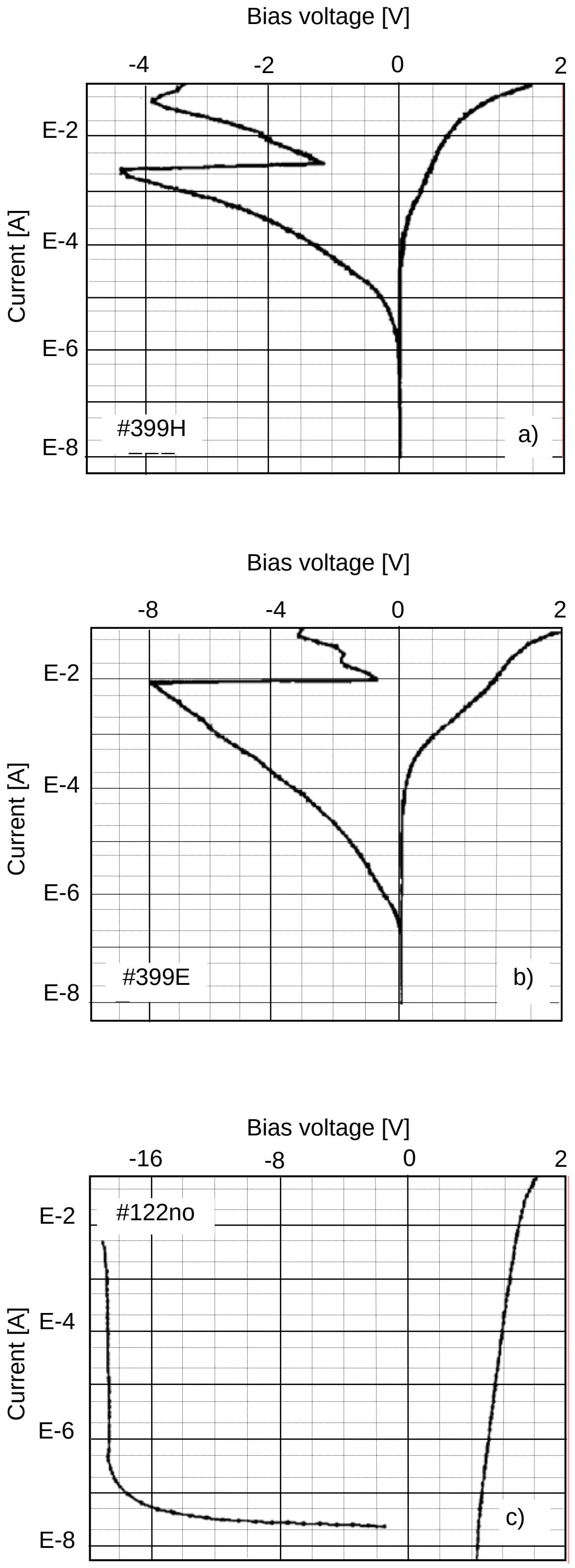

Fig. 2. Current-voltage dependence for AlGaAs/InGaAs SCH SQW lasers, which P-I characteristics are presented in Fig. 1: a) the laser of the type I, b) the laser of the type II. For comparison I-V curve for AlGaAs/GaAs GRIN SCH SQW laser of the type III, which had one level Cr/Pt metallisation restricted to the contact stripe, is shown in Fig. 2c.

ohmic contact to the p^+-GaAs contact layer. On the other hand the lateral current confinement is assumed to be achieved in the devices as a result of the high contact resistance between the Cr/Pt – alloy and p-AlGaAs cladding layer that is lower doped intentionally than the p^+-GaAs contact layer. Let us note that the I-V characteristics, presented in Fig. 2a and b, exhibit a relative symmetry. This is due to the Schottky-barrier formation outside the ridge and the fact that it is reverse biased whereas the p-n junction is forward biased or *vice versa*. On the basis of the results presented in Fig. 2a and b, it may be seen that in the characteristics there exists a big difference between the two data. The devices with the Au montage layer show much higher currents and the “breakdown voltage” is nearly two times lower.

To explain such a difference, cross-sectional views of lasers taken by means of SEM (Fig. 3) have been analysed. It has been found that mesa etched sides form more or less vertical planes. As seen in Fig. 3b metal does not stick to the sidewall if the etched ridge is of a rectangular shape. In the latter case if the surface is not covered with Au, the current spreading is confined to the region just below the stripe. However, in other cases, that is in the presence of the montage layer or if the mesa shape is not rectangular (Fig. 3a), the current may flow the entire surface and such a structure is likely to suffer from having a large leakage current. In this context the quality of the (Cr/Pt)/p-AlGaAs Schottky contact is substantially important, since it is assumed to govern the performance of the devices studied.

Schottky barrier formation on the damage surface is quite a general problem. It has been found that the Schottky barrier height may be influenced by different radiation damage [4]. For example, data for the Pt/p-GaAs system indicate an ohmic behaviour even at a relatively low level of doping ($5 \cdot 10^{16}$ cm^{-3}) if Pt is fabricated by electron-beam deposition. Deposition of metals by Ar sputtering could also introduce damage on the GaAs surface, thereby; it can have a great influence on the electrical characteristics of the Schottky diode as shown in Refs. [5, 6]. Moreover, the necessity of the high doping ($5 \cdot 10^{17}$ cm^{-3}) and additionally, relatively low Al content (x = 0.3) in the p-AlGaAs cladding layer (in AlGaAs/InGaAs lasers) are not favourable in obtaining Schottky barrier of a good quality.

Moreover, the p-AlGaAs surface outside the stripe is also seriously damaged, since it is subjected to ion bombardment during dry etching. A common disadvantage of such an ion irradiation is the generation of surface states; those may affect various properties of samples [7]. Pearton et al. [8] have found that ion bombardment causes irreversible damage in p-n GaAs diode. This is evidenced by an increase in the ideality factor, which means that deep level recombination centres are introduced into material during plasma exposure and high leakage

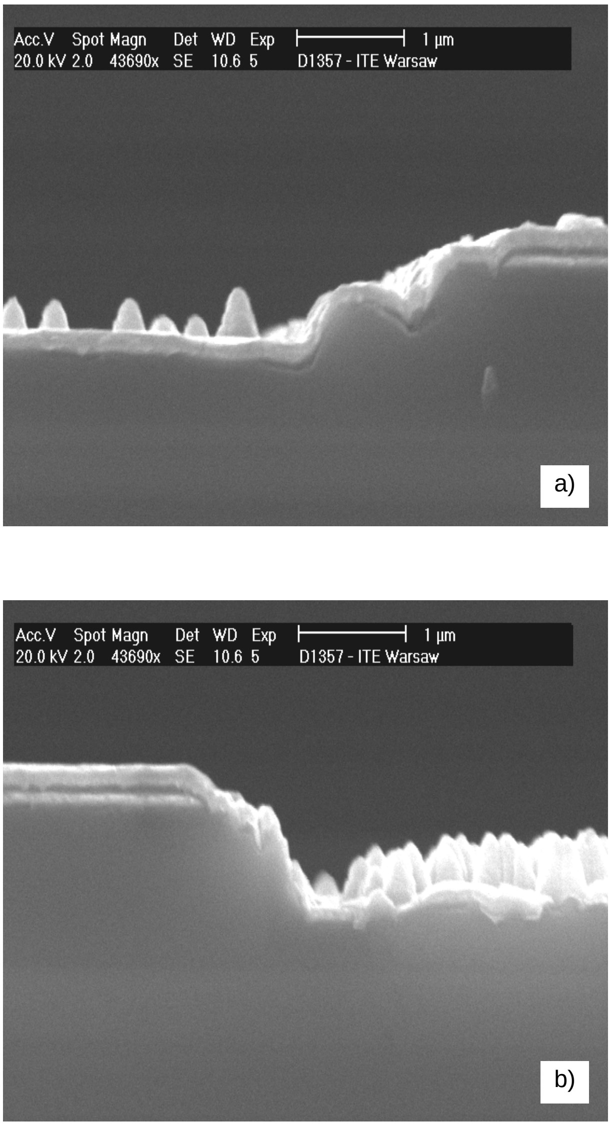

Fig. 3. Cross-sectional views of the etched mesa after two step metallisation with Cr/Pt in lasers without the contact montage layers. Images were taken with scanning electron microscope.

currents in p-n junction due to recombination processes are produced. On the basis of the results mentioned above and our results presented we conclude that the rectifying behaviour of the (Cr/Pt)/p-AlGaAs diode is not effective in the confining of the current spreading in the lasers studied. The poor performance in the electrical characteristics is most probably attributed to the presence of the defects introduced by dry etching and sputtering in the vicinity of the (Cr/Pt)/p-AlGaAs interface. Their presence manifests itself in the dramatic increase in the forward current if Au metallisation extends over the entire bombarded surface. Consequently, the increase in leakage current and poor electrical confinement result in a lowered reliability of the devices.

DLTS spectra obtained for the control sample and Ar-ion beam etched AlGaAs:Si are compared in Fig. 4. Two deep electron traps with thermal activation energies E_C –0.42 eV and E_C –0.79 eV revealed in the DLTS spectrum of the reference sample can be attributed to the well known DX(Si) centre and ME6 trap, respectively [9, 10]. It seems obvious from the DLTS measurements that dry etching leads to an appearance of three broadened peaks. These peaks indicated arrows in Fig. 4b. Extra efforts are necessary to characterise the defects. However, those positioned in the higher temperature region, may be considered as good candidates responsible for the effects observed.

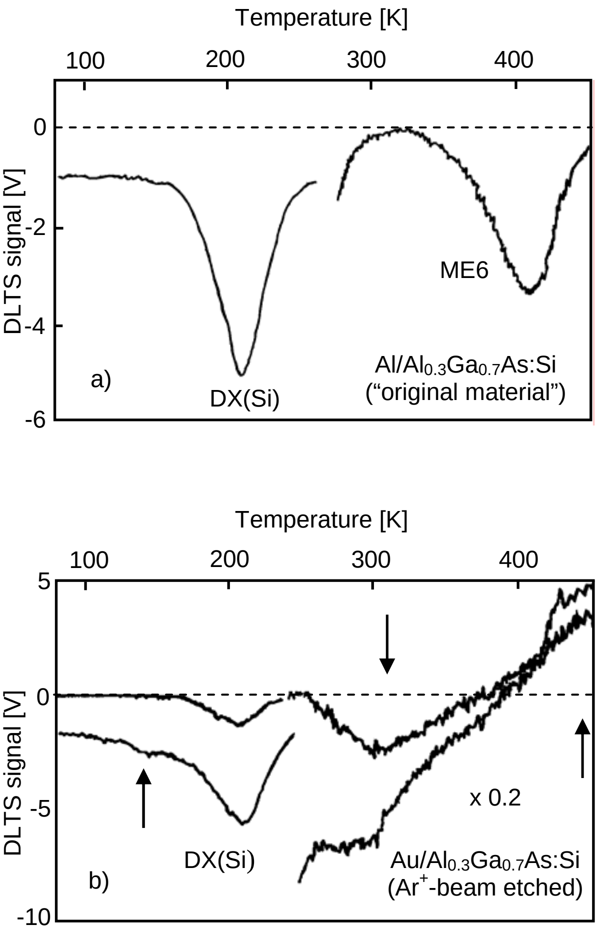

Fig. 4. Typical DLTS spectra of $Al_{0.3}Ga_{0.7}As$:Si: a) original material, b) material after Ar-ion beam etching. The value of reverse bias was equal to V_R = –0.5V and the voltage level during filling pulses was 0 or +0.5V. The spectra were obtained for emission rate e_n = 103 s^{-1} and filling pulse duration time t_C = 1 ms. The arrows show the positions of three broadened peaks related to the dry etching.

The strongest support has been provided for the explanation by the absence of anomalies in the characteristics for first group lasers in which metallisation was restricted just only to the contact stripe. The effectiveness of the lateral current and light confinement in these lasers has been proved by results of measurements of the far-field intensity distributions (not presented here). The broad-area contact lasers showed operation typically in multi-longitudinal, fundamental transverse and higher lateral modes stable up to $8I_{th}$ if was evaluated at room temperature under pulsed current conditions. The P-I characteristics of the lasers showed no kinks and nonlinearities in the range of light powers investigated up to 140 mW and 5 W under continuous wave and pulsed operation, respectively.

4. Conclusions

In conclusion, it may be noted that a plasma exposure during processing steps induces a number of the surface defects that can be enough to degrade the performance of broad-area contact ridge waveguide lasers. Consequently, the presence of the surface defects and a lack of the current spreading confinement lead to anomalous characteristics of the multimode lasing devices.

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