SELFALIGNED METALLIC CONTACTS ON GaP : N-LEDs PROCESSED BY LASER PULSE IRRADIATION-INDUCED ABLATION

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SELFALIGNED METALLIC CONTACTS ON GaP:N-LEDs PROCESSED BY LASER PULSE IRRADIATION-INDUCED ABLATION

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Resumé

Les contacts arrières de diodes electroluminescentes en GaP:N sont autoalignés par rapport aux contacts frontaux à l'aide d'un procès d'ablation. Ceci est obtenu par l'irradiation avec une seule impulsion de laser ruby. Les contacts frontaux qui servent de masques ne sont pas endommagés par la lumière intense du laser qui doit traverser la surface frontale pour atteindre l'interface arrière entre la GaP et la couche métallique en or. Les parties de la surface du GaP où la couche d'or est soufflée en raison de la haute tension de vapeur du phosphore montrent une surface très irregulière par suite d'une concentration statistique de la lumière réflectée à l'interface rugueuse GaP-Au.

Quelques propriétés du processus d'ablation sont décrites à l'aide d'un modèle assez simple.

Abstract

Rear Au-contacts of GaP:N-LEDs are selfaligned structured as to the front contacts by a single ruby laser pulse irradiation-induced ablation process. The front contacts acting as masks are not damaged by the intensive laser light which must pass the front surface in order to reach the rear GaP/Au-interface. The areas of the GaP-surface where the Au-contact layer is removed exhibit a very irregular shape, caused by excess evaporation of GaP due to focusing reflections of the laser light at the GaP/Au- contact interface, and therefore reduced optical cross-talk. Some of the features of the ablation process are explained by a simple theoretical model.

1. Introduction

Electronic devices are manufactured by a great number of sophisticated structuring processes, partially involving elaborate mask technology of high complexity. The quality of these processes determines the production yield.

Laser processing, for instance the annealing of ion-implanted wafers or alloying contacts, has opened new aspects. The physical process times are reduced by more than ten orders of magnitude. Deleterious contamination due to impurity atoms,which diffuse from the surface into the solid during conventional high temperature processes and cause deep levels,can be minimized.

Laser pulse irradiation, however, may have also other advantages. The transparency of semiconductors to laser radiation of certain wavelengths allows e.g. selfaligned structuring or alloying of device contacts on the rear of a wafer. This can be of particular advantage for light emitting diodes where the metal layers serve a twofold purpose: they have to provide ohmic contacts and influence the optical outcoupling of the light, which is generated inside the diode crystal, by size and reflectivity.

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In the following a laser pulse irradiation-induced ablation process for structuring rear contacts of light emitting diodes is described. The process additionally produces a surface structure with reduced optical reflectivity at those areas where the metallization was removed. Hence this effect can be advantageously utilized to reduce optical cross-talk in monolithic LED-displays with transparent substrates. The results obtained on GaP:N will be described and discussed in terms of a simple theoretical model.

2. Experiments

The experiments were carried out on standard wafers of green GaP:N-LEDs. These contain a sequence of p- and n-conducting epitaxial layers produced by liquid phase epitaxy on the top of an n-conducting substrate and are metallized on the p-side by evaporating an Au/Zn-alloy which is subsequently structured to a dot pattern by photolitho graphy and on the n-side by a full area Au/Ge-contact(Fig. 1a). The

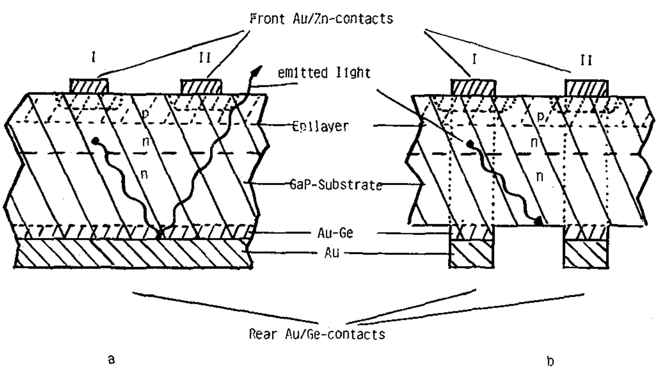

Fig.1 Laser-pulse irradiation-induced ablation for structuring the rear Au/Ge-contacts of LEDs; a) conventional system, b) structure to be made

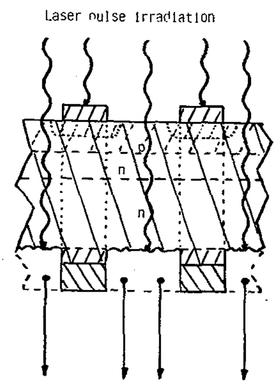

Fig.2 Laser-pulse irradiation-induced ablation

latter one provides a rather high reflectivity even after the alloying process is performed. The high reflectivity is useful to enhance the optical efficiency of individual LEDs prepared out of the wafer, but is deleterious for monolithic LED-arrays due to severe optical cross-talk between adjacent elements as indicated in Fig. 1a. This effect can be minimized by removing the n-side metallization to such an extent that only a small area beyond the p-contact is left in order to provide the ohmic contact and by depositing a highly absorbing layer, for instance of polycrystalline silicon /1/ on this n-side surface.

According to conventional processing the structuring of the n-side contacts would require the proper aligning of the photolithographic mask with respect to the p-side contacts and subsequent deposition of the absorbing layer on the n-side which, however, must be structured to have holes at those places where the n-metallization is left (Fig. 1b).

Instead of carrying out this complicated procedure we irradiated the front of the wafer with an intensive light pulse of a length of 20 ns and an energy density of 1 J/cm^2 emitted at a wavelength of 694.3 nm by a ruby laser. The GaP- sample does not absorbe much light of such wavelengths because the photon energy is less than the gapwidth of the forbidden band but too high at the applied energy densities of 1 J/cm^2 for a strong free carrier absorption utilized, for instance, in annealing ion-implanted silicon with the 10.6 μm pulse radiation emitted by a CO_2-laser /2/. Free carrier absorption is of great weight for GaP when irradiated with a pulse of the energy density, say, above 2 J/cm^2 emitted by a ruby laser leading to destruction of a thin surface layer of the front side of the wafer. Under these conditions, the laser light does not reach the rear side anymore.

The light not reflected at the interface between GaP-substrate and Au/Ge-rear contact is absorbed in the thin Au/Ge-layer of the rear contact film. The absorbed energy converted into heat raises the temperature of the thin Au/Ge-layer adjacent the interface. Since the front contact is highly reflecting for the laser light and the rear contact only weakly the energy density of the light pulse can be chosen such that the temperature of the rear contact increases considerably whilst the front contact is not affected at all. The rear contact serves as heat source for the adjacent GaP-substrate layer where the GaP-molecules disintegrate and evaporating phosphorus causes a high gas pressure at the GaP-Au/Ge-interface. The solid or liquid Au/Ge-film is consequently blown away everywhere from these zones which are heated up by the laser light pulse. The extremely small divergence of the laser beam ensures the perfect projection of the front contacts onto the rear surface (Fig. 2).

Fig. 3a shows the light optical micrograph of the detail of the front side of a wafer containing an array of Au/Zn-contact elements and Fig. 3b the rear of the wafer covered with a uniform Au/Ge-contact layer. Fig. 3c shows the rear of the wafer after the laser-pulse irradiation-induced ablation and demonstrates the efficiency and precision of this process. A considerable part of the GaP-substrate evaporates too if the energy density of the light pulse is high enough as for instance in case of the sample of Fig. 3c. The rear side of the wafers used in these experiments are lapped before metallization. A detail of the surface structure before laser pulse irradiation is shown by the electron optical micrograph (SEM) of Fig. 4a and after irradiation by that of Fig. 4b.

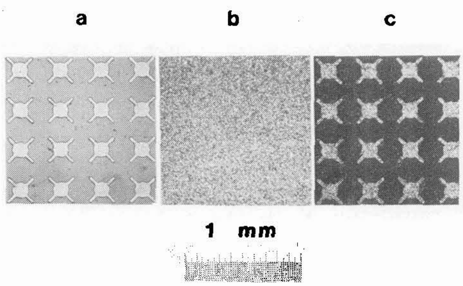

Fig.3 Laser-pulse irradiation-induced ablation for selfaligned structuring of rear Au/Ge-contacts of GaP:N-LEDs
a) front Au/Zn-contact, b) uniform rear Au/Ge-contact before laser pulse-irradiation, c) self-aligned rear Au/Ge-contact structures processed by laser irradiation-induced ablation

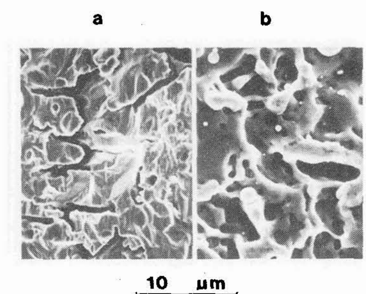

Fig.4 Laser-pulse irradiation-induced ablation of rear Au/Ge-contact layers of GaP:N-LEDs; REM-micrographs
a) rear Au/Ge-contact layer before laser pulse irradiation, b) rear surface of GaP:N after ablation of rear Au/Ge contact layer by laser pulse irradiation.

Those parts of the wafer surface where the Au/Ge-rear contact layer is blown away exhibit the very peculiar effect of light optical reflection properties reduced by almost a factor of five because incident light peters out or passes through the interface GaP/air and is lost. The effect is demonstrated by Fig. 5 where the logarithm of the intensity I of the light emitted by an active diode before irradiation and by one after irradiation is plotted versus the lateral distance y along the wafer surface. Consequently, the novel methode is very well suited in manufacturing diode arrays with considerable reduced light optical cross-talk as indicated in the schematic drawing of Fig. 1b.

3. Theoretical Model

3.1. Fraction of absorbed light

Auger-electron spectrometry indicates exponential concentration profiles of the different components of the GaP/Au-system inside the transition layer (Fig. 6). We assume that the very thin transition layer entitles to determine the fraction of the laser light absorbed at the interface between GaP-substrate and Au-contact using an exponential dependence of the refractive indices of the system (Fig.7) in accordance with the exponential concentration profile of the components of the transition layer. Interference and polarization are neglected under the condition of perpendicular incidence of light on a rough interface. Since the complex refractive index is a one dimensional continuous function perpendicular to the surface taken as the x-axis the normalized intensity I/I_0 absorbed at the interface may be described by

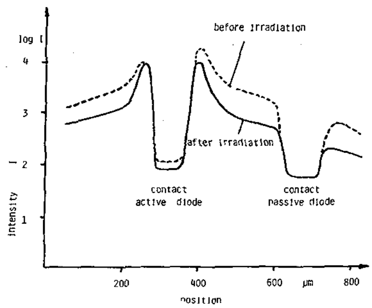

Fig.5 Reduction of optical cross-talk in LED-arrays due to laser-pulse irradiation-induced ablative structuring of rear Au/Ge-contacts. The logarithm of the intensity I emitted by one active diode is plotted versus the relative position

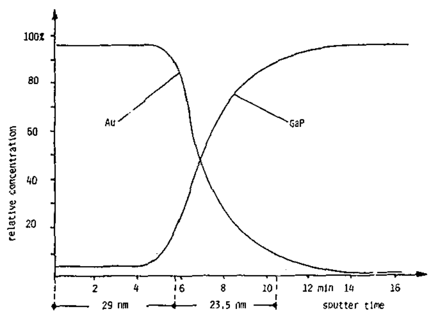

Fig.6 Auger electron spectroscopical analysis of the GaP/Au concentration profile in the transition layer of a Au-Ge rear contact on a GaP:N-LED

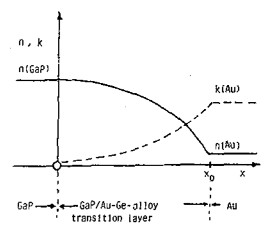

Fig.7 Refractive indices n, k schematically plotted versus distance x in the transition layer

$$I/I_0 = 1 - \exp\left\{-\frac{4\pi}{\lambda}\int_0^{x_p} k(\xi)\,d\xi\right\}\frac{[n(Au) - \bar{n}]^2 + [k(Au) - \bar{k}]^2}{[n(Au) + \bar{n}]^2 + [k(Au) + \bar{k}]^2} \qquad (1)$$

The distance x_p of the Au-layer to the origine of the coordinate system (Fig.7) is chosen so, that the imaginary refractive index k(x) of the GaP/Au-transition layer does not differ more than 10% from k(GaP) at x = 0. The mean values of $\bar{n}$ and $\bar{k}$ are defined by

$$\bar{n} = \int_0^{x_p} n(\xi)\,d\xi \Big/ \int_0^{x_p} d\xi \quad (2) \qquad \text{and by} \qquad \bar{k} = \int_0^{x_p} k(\xi)\,d\xi \Big/ \int_0^{x_p} d\xi \quad (3)$$

Eq. (1) was evaluated with the parameters n(Au)=0.35, k(Au)=1.79, n(GaP)=2.91, k(GaP)=0, $\lambda = 6.9\cdot10^{-5}$cm, $x_p = 2.35\cdot10^{-6}$cm resulting in 28% reflected light and 72% absorbed ones. The reflection coefficient at the interface GaP/air is 0.24 so that finally 55% of the incident light pulse of 1 J/cm^2 are absorbed and converted into heat at the rear Au/Ge-contact.

3.2. Temperature profile in the Au/Ge-contact

Being mainly interested on the start of the ablation we do not need to solve the inhomogeneous differential equation for heat transport /3/,/4/ but can use the analytical source solution for semi-infinite specimen

$$T \sim (\pi \kappa t)^{-1/2} \exp\left\{-x^2/(4\kappa t)\right\} \quad (4) \quad \text{of} \quad \partial T/\partial t - \kappa \partial^2 T/\partial x^2 = 0 \quad (5)$$

because of fast temperature rise of the GaP/Au-interface. The differences of 10 to 20% in the results can be tolerated. Fig. 8 shows the calculated temperature profiles where the latent heat of fusion is 64 Jg^{-1}, κ(1336 K,sol.)=0.915 cm^2/s, κ(liq.)= 0.4 cm^2/s.

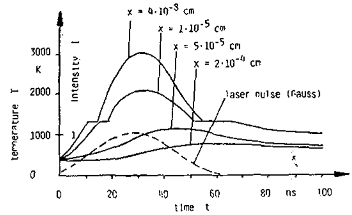

Fig.8 Calculated temperature profile in a semi-infinite Au-sample irradiated with ruby laser pulse; energy density E = 0.55 J/cm^2, pulse width D = 20 ns; parameter: depth x in Au-sample

The disintegration of the GaP-molecule starts at approximately 973 K so that the high phosphorus pressure causes the ablation process already during the very first nanoseconds. It has finished before the heat wave reaches the outer surface of the Au-contact layer and is "reflected" there. Locally, much higher temperatures than calculated ones will be reached in the GaP due to focusing light reflections at the rough interface explaining the strong local erosion of the GaP surface (Fig. 4b).

4. Discussion and Conclusion

The variation of the irradiation energy density from 0.5 to 2 J/cm^2 shows the agreement between experiment and model discussed which proves to be accurate enough in describing the general features of the processes going on. More detailed analysis is not accessible to mathematical treatment, because the irregular GaP/Au-interface serving as heat source defies each precise calculation.

The advantage of the novel method is in a very simple, uncritical and contamination free process. The diodes already manufactured are not damaged. The areas of the rear surface of the wafer, which suffered ablation, become very irregular with the consequence of strongly reduced quality of reflection. This effect can be utilized to the best advantage in designing, for instance, monolithic LED-displays with reduced optical cross-talk on transparent substrates.

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