Pd/In-based Ohmic Contacts to n-GaAs

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***Abstract* — The contribution deals with the performance of doping element/Pd/In contact structures on n^+-GaAs wafers where Ge, Sn or Si were employed as doping elements. The contact structures were deposited by high vacuum evaporation. Ohmic behaviour of the structures was achieved either by rapid thermal annealing (RTA) or by laser annealing by YAG:Nd power laser. Electrical properties were measured by four-point modified method. In addition the influence of absorbing cap layer was studied.**

I. Introduction

Gallium arsenide and other group III-V semiconductors have found numerous applications in the electronics industry because of such characteristics as the direct band gap and higher electron mobility, which make them more suitable than silicon in the fabrication of optoelectronic and high-frequency devices [1]. These devices are operated at high current densities and, as technology develops, are continually undergoing a reduction in size. In order to link the active regions of the semiconductor devices to the external circuit, contacts with low electrical resistance (ohmic contacts) are required. The main requirements of ohmic contacts are that they should have low contact resistance, be thermally stable and have good adhesion and lateral uniformity. These are all directly affected by the microstructure of the contact [2].

In this study attempts were made to form a low band gap interfacial phase of $In_xGa_{1-x}As$ to reduce the barrier height at the metal/semiconductor junction, thus yielding low resistance, highly reliable contacts. Since the barrier heights of the metal/ $In_xGa_{1-x}As$ contacts are measured to be lower than that of the metal/GaAs contacts [3], the electrical current is believed to flow primarily through the metal/ $In_xGa_{1-x}As$/GaAs interface.

Annealing is a very important step in the preparation of ohmic contacts and is carried out using various technologies. The most frequently used methods include classical furnace annealing, annealing with an electron beam, RTA (rapid thermal annealing) using high-power discharge lamps and also laser annealing. The latter method has the advantage that it permits the use of very short exposure times, during which only a very thin surface layer is heated and the area subjected to the thermal stress corresponds to the size of the laser beam spot. In addition, the extremely high cooling rates permit the introduction of dopant concentrations that exceed the equilibrium solubility.

This study is a portion of a complex effort directed to improve the electrical properties of ohmic contacts to n-GaAs. Optimization of doping elements [4,5], deposition methods [5], inert atmosphere during annealing [6], absorption-capping layers [4,5,7], cleaning solutions (wet etching) [7], alloying methods [7], glow-discharge cleaning (dry etching) [8], Ti surface layer [9] was carried out previously. In this paper the investigation is focused on Pd/In based ohmic contacts to GaAs where Ge, Sn or Si are employed as doping elements. The other part is dedicated to the ohmic contacts with absorbing-capping layer. The contacts are prepared by RTA and laser annealing.

II. Experimental

N-type GaAs:Si substrate plates (the doping level of $2.0x10^{18}$ cm^{-3}) were used in our experiments. The surface of plates were etched with a mixture of $5H_2SO_4$:$1H_2O_2$:$1H_2O$ for a period of 30 s, washed with distilled water and dried. Standard optical lithography was employed to form a resist mask on the surface of the plates with a pattern designed for measuring contact resistance. The test contact patterns were created after deposition of metallization by the lift-off technique. There is more about contact preparation in [10].

The metallizations were deposited by high vacuum evaporation except of absorbing cap layer that was deposited by sputtering. High vacuum evaporation was carried out at UNIVEX 450 apparatus. This evaporator consists of oil pump and turbomolecular pump that quarantee deposition in good conditions; pressure during evaporation was approximately 2 x 10^{-6} mbar. Sputtering was performed in sputter coater-SCD 050, BAL-TEC. The deposition was provided in argon inert atmosphere. The pressure during sputtering was about 2 x 10^{-2} mbar.

Prior the deposition of metallization the surface of plates was cleaned by a mixture of H_2SO_4:H_2O_2:H_2O (1:8:500) for 30 s followed by HCl 35% for 2 min. The substrates were blow dried immediately using N_2.

The annealing of the structures was carried out using RTA (rapid thermal annealing) with 5 halogen lamps (each with the power of 1 kW) in Ar atmosphere. To compare the influence of RTA and laser annealing, YAG:Nd power laser working in the Q-switching regime was used. The wavelength of the radiation was 1060 nm, impulse length 350 ns, pulse energy variable in the range from 0 to 0.3 J/cm^2, the repetition rate was 500 Hz. The laser annealing was performed in the argon inert atmosphere. The specific contact resistivities were measured by the four-point modified method. The measuring current was 10 mA.

Metallization	Substrate	Doping element [5 nm]	Annealing
Pd/In	n-GaAs	none	Laser, RTA
Ge/Pd/In	n-GaAs	Ge	Laser, RTA
Sn/Pd/In	n-GaAs	Sn	Laser, RTA
Si/Pd/In	n-GaAs	Si	Laser, RTA
Pt/Ge/Pd/In	n-GaAs	Ge	Laser, RTA
Pt/Sn/Pd/In	n-GaAs	Sn	Laser, RTA
Pt/Si/Pd/In	n-GaAs	Si	Laser, RTA

Tab. 1 Summary of contact structures with and without Pt absorbing-capping layer

III. Results and Discussion

Two sets of contact metallizations summarized in Tab. 1 were prepared in order to find the best doping element with its influence on the specific contact resistivity and optimal conditions of an annealing process performed by RTA or power laser YAG:Nd.

A Contacts without Pt absorbing-capping layer

The *doping element(5nm)/Pd(5nm)/In(18nm)-GaAs* based contact structures with different doping element (Ge or Sn or Si) were investigated. The specific contact resistivity values are plotted as a function of the energy density of laser radiation in the process of laser annealing in Fig. 1.

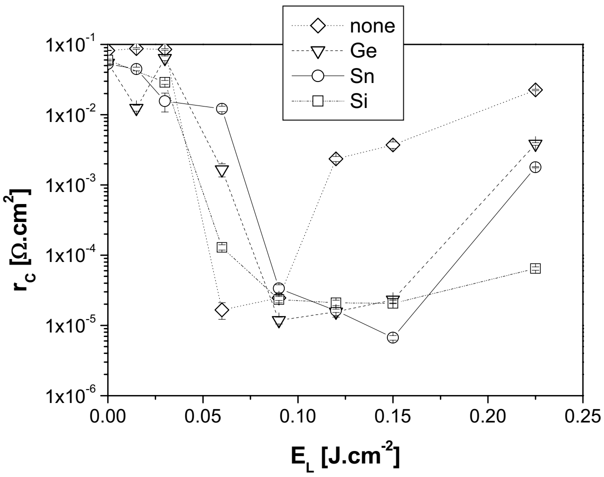


Fig. 1 The dependence of contact resistivity r_C on energy density of laser radiation E_L for different doping elements

There are four different curves at the Fig. 1, three of them represent the contact structures with different doping element and the fourth one is structure without doping element. It serves as a comparison if doping elements influence the values of specific contact resistivity in these structures and how.

The curve representing the structure without doping element (in the Fig. 1 in legend marked as "none") exhibits the lowest value of contact resistivity r_C= $(1.66 \pm 0.44)x10^{-5}$ $\Omega.cm^2$ at energy density of E_L= 0.06 $J.cm^{-2}$. The structure with Ge as a doping element presents the lowest value of contact resistivity r_C= $(1.18 \pm 0.13)x10^{-5}$ $\Omega.cm^2$ at energy density of E_L= 0.09 $J.cm^{-2}$ while the absolute lowest value of r_C= $(6.67 \pm 0.50)x10^{-6}$ $\Omega.cm^2$ at energy density of E_L= 0.15 $J.cm^{-2}$ displays the contact structure with Sn as doping element. The contact structure with Si exhibits the lowest value of r_C= $(2.06 \pm 0.15)x10^{-5}$ $\Omega.cm^2$ at energy density of E_L= 0.15 $J.cm^{-2}$. The lowest value of contact resistivity for contact metallization without doping element was reached at lower value of energy density of 0.06 $J.cm^{-2}$ while with increase of energy density the contact resistivities deteriorate much. The minimum contact resistivities for contact structures with Ge and Sn as doping elements were obtained at higher energy densities and with increase of energy density up to the maximum the contact resistivities stay lower than in the case of the contact structure without doping element. Dependence of the contact resistivities in the case of Si is different. At the energy density of 0.09 $J.cm^{-2}$ broad minimum of contact resistivities is reached and with increase of energy density the contact resistivities stay almost invariant except of the maximum energy density applied.

Rapid thermal annealing (RTA) carried out for 45 s in the range of temperatures from 390°C to 620°C and its influence on the values of specific contact resistivity was tested on samples without Pt capping layer. The results are shown in Tab. 2a,b.

Temp. [°C]	r_C [$\Omega.cm^2$]	Temp. [°C]	r_C [$\Omega.cm^2$]
	Pd/In -GaAs		Ge/Pd/In -GaAs
404	$2,52x10^{-2}$	398	$3,23x10^{-2}$
496	$1,84x10^{-5}$	490	$1,76x10^{-2}$
578	$1,13x10^{-5}$	586	$7,68x10^{-6}$
618	$7,67x10^{-2}$	604	$1,86x10^{-5}$

Tab. 2a The survey of contact resistivities for Pd/In-GaAs and Ge/Pd/In-GaAs contact structures annealed by RTA

The lowest value of specific contact resistivity r_C= $(7.68 \pm 0.52)x10^{-6}$ $\Omega.cm^2$ at temperature of 586 °C was obtained for sample with Ge as a doping element. That is the only contact structure that exhibits lower value of specific contact resistivity than the contact structure without doping element with its best value of contact resistivity r_C= $(1.13 \pm 0.11)x10^{-5}$ Ω.cm^2 that was obtained at temperature of 578 °C.

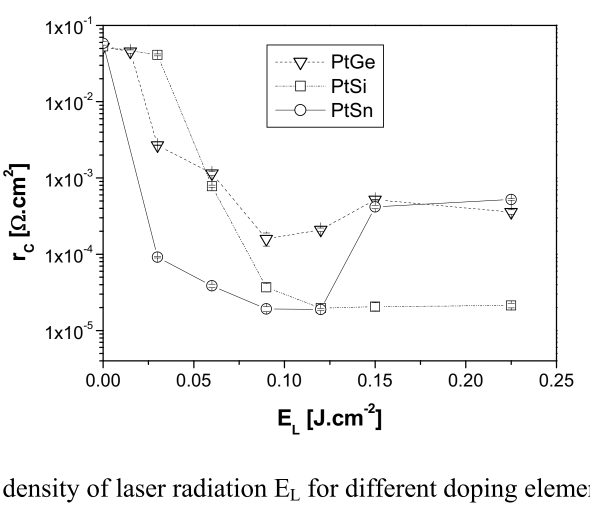
Temp. [°C]	r_C [Ω.cm^2]	
	Sn/Pd/In -GaAs	Si/Pd/In -GaAs
394	3.69x10^{-2}	3.66x10^{-2}
456	1.18x10^{-2}	1.88x10^{-3}
508	5.97x10^{-4}	3.74x10^{-5}
558	1.92x10^{-5}	1.76x10^{-4}
604	7.33x10^{-4}	2.99x10^{-2}

Tab. 2b The survey of contact resistivities for Sn/Pd/In-GaAs and Si/Pd/In-GaAs contact structures annealed by RTA

B Contacts with Pt absorbing-capping layer

The contact structures tested are summarized in Tab. 1. Absorbing-capping layer is used for complete absorption of the incident laser radiation and for the homogenous distribution of the absorbed heat into the contact structure. In our case double Pt layer was used. First layer was high vacuum evaporated and the second sputtered for better absorption of laser radiation [7]. The contact structures *Pt(12nm-sputtered) /Pt(50nm) /doping element(5nm)/Pd(5nm)/In(18nm)-GaAs* were examined. The specific contact resistivity values are plotted as a function of the energy density of laser radiation in the process of laser annealing in Fig. 2.

Fig. 2 The dependence of contact resistivity r_C on energy



density of laser radiation E_L for different doping elements

The worst parameters of specific contact resistivities present the contact structure with Ge as a doping element in the whole range of energy densities applied. Its best value of r_C= $(1.59 \pm 0.31)x10^{-4}$ Ω.cm^2 was obtained at energy density of E_L= 0.09 J.cm^{-2}. Conversely the lowest values of specific contact resistivity exhibit the contact structure with Sn as a doping element up to the energy density of E_L= 0.12 J.cm^{-2}. Its lowest value of r_C= $(1.89 \pm 0.06)x10^{-5}$ Ω.cm^2 was obtained at energy density of E_L= 0.12 J.cm^{-2}. Its worth noting that increase of energy density above E_L= 0.12 J.cm^{-2} results in aggravation of the values of specific contact resistivity by approximately one order of magnitude. The contact structure with Si as a doping element presents the lowest values of specific contact resistivity in the range of energy density from 0.15 J.cm^{-2} to 0.225 J.cm^{-2}. Its best value of r_C= $(1.97 \pm 0.13)x10^{-5}$ Ω.cm^2 was obtained at energy density of E_L= 0.12 J.cm^{-2}. The lowest values of specific contact resistivity are almost identical for contact structures with Sn and Si as doping elements.

Rapid thermal annealing (RTA) was carried out for 45 s in the range of temperatures from 394°C to 604°C. The values of specific contact resistivity for each of the contact metallizations varied from 10^{-2} Ω.cm^2 to 10^{-3} Ω.cm^2 for the whole range of temperatures applied.

IV. Conclusion

Two sets of contact structures with and without Pt absorbing-capping layer were prepared. The influence of different doping element on the electrical properties of the contacts was examined. The contacts were prepared either by laser annealing using power laser YAG:Nd or by rapid thermal annealing (RTA).

Contact structures without Pt absorbing layer:
The lowest value of r_C= $(6.67 \pm 0.50)x10^{-6}$ Ω.cm^2 was obtained for Sn as a doping element in the case of contact structures prepared by laser annealing. Not much worse parameter of r_C= $(7.68 \pm 0.52)x10^{-6}$ Ω.cm^2 was obtained in the case of contact structure prepared by RTA with Ge as a doping element.

Contact structures with absorbing Pt layer:
In general the contact structures with Pt absorbing layer present higher values of specific contact resistivity comparing with the structures without Pt absorbing layer. The lowest value of r_C= $(1.89 \pm 0.06)x10^{-5}$ Ω.cm^2 was obtained for Sn as a doping element in the case of contact structures prepared by laser annealing. The RTA is not appropriate method for the preparation of ohmic contacts in this case.

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