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Citation for published version (APA):
Shen, L., Veldhoven, van, P. J., Jiao, Y., Dolores Calzadilla, V. M., van der Tol, J. J. G. M., Roelkens, G. C., & Smit, M. K. (2015). Low optical loss ohmic contacts on heavily doped N-type InGaAs for InP membrane devices. In *The 27th International Conference on Indium Phosphide and Related Materials (IPRM), 28 June - 2 July 2015, Santa Barbara, USA* (pp. 177-178). Institute of Electrical and Electronics Engineers.

Document status and date:
Published: 01/01/2015

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

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Low Optical Loss Ohmic Contacts on Heavily Doped N-type InGaAs for InP Membrane Devices

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Recent developments in membrane photonics promise enhanced performances for integrated devices and circuits [1]. One remaining technological challenge for membrane photonic devices lies in the n-type ohmic contacts on top of active devices. From the electrical point of view, the contact resistance needs to be minimized for devices with ever-smaller sizes to achieve high speed and low power consumption. Moreover, low optical loss from those metal contacts is required for devices integrated in a membrane with only submicron thickness.

Conventional Au/Ge/Ni n-type ohmic contacts provide low contact resistance for InP based devices after annealing. However, the high optical absorption of Ni limits its use in membrane devices. Furthermore, the high temperature annealing process causes strong spiking of Au into semiconductor layers [2]. Our recently developed Ag/Ge contacts show both ohmic behavior and low optical loss [3]. The use of Ge instead of metal as the first deposited layer results in low optical absorption in the telecommunication wavelength range. The spiking effect is also reduced in the Ag based contacts compared with the Au based ones, as a result of a much higher eutectic temperature of the Ag/Ge alloy. However, the annealing process still introduces degradation in the contact interface and thereby increases the optical loss. Also, the contact resistance needs to be further reduced to approach the level of Au/Ge/Ni contacts.

In this work we present an improved solution of the Ag/Ge contact to obtain a lower resistance and a lower optical loss. By making use of the higher solubility of the n-type dopants (Si) in InGaAs as compared to InP, we obtain a contact layer of n-$In_{0.53}Ga_{0.47}As$ heavily doped up to 2×10^{19} cm^{-3}. Table 1 shows the average specific contact resistances of different contacts measured with the circular transfer length method (CTLM). The higher doping concentration in the InGaAs contact layer leads to lower contact resistances compared with those from contacts on InP (doped at 2×10^{18} cm^{-3}). Moreover, an ohmic contact with low resistance is formed in InGaAs contacts even without annealing. This is normal for heavily doped surfaces where the tunneling effect is sufficiently strong. This annealing-free process prevents many high-temperature related problems for membrane devices, including degradations of the contact interface. Hence, a lower optical loss compared to those from annealed contacts is expected. In order to measure the optical loss from contacts at 1550 nm, a standard approach as described in [3] is used. The membrane waveguide (WG) structures used in this measurement are shown in Fig. 1. The measured WG insertion loss from Ag/Ge/InGaAs contacts is plotted in Fig. 2 together with previous results from Ag/Ge/InP and Au/Ge/Ni/InP contacts. It is clear that the propagation loss is further reduced in this new contact. It should be noticed that the starting point of the series of Ag/Ge/InGaAs is higher than those from the others. This is because the InGaAs layer introduces extra loss. This extra loss is characterized in another array of InGaAs/InP WGs without metal contacts. From the results in Fig. 3 a propagation loss of 0.018 dB/µm can be extracted, which is an order of magnitude lower than those from the metal contact, implying that the InGaAs loss is negligible compared to contact loss. A material absorption coefficient of 300/cm is calculated based on the propagation loss value and the confinement factor of the guided mode in the InGaAs layer. Compared with the absorption coefficient of 7000/cm in intrinsic InGaAs, a significant reduction of the inter-band absorption due to the band-filling effect in heavily doped n-type materials is observed [4].

In summary (Table 2), a Ag/Ge/InGaAs contact is developed to provide an annealing-free n-type ohmic contact with low contact resistance and low optical loss. It is promising for high-performance InP membrane photonic devices.

References

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Table 1. Specific contact resistances of different contacts, measured both before and after a 15 s annealing at 400 °C.

Contact type	Specific contact resistance (Ωcm^2)	
	Before annealing	After annealing
Au/Ge/Ni/InP	Non-Ohmic	4.0×10^{-7}
Ag/Ge/InP: 2 nm Ge	Non-Ohmic	2.6×10^{-5}
Ag/Ge/InP: 15 nm Ge	Non-Ohmic	1.8×10^{-6}
Ag/Ge/InGaAs: 2 nm Ge	7.2×10^{-7}	1.4×10^{-7}
Ag/Ge/InGaAs: 15 nm Ge	Non-Ohmic	1.9×10^{-7}

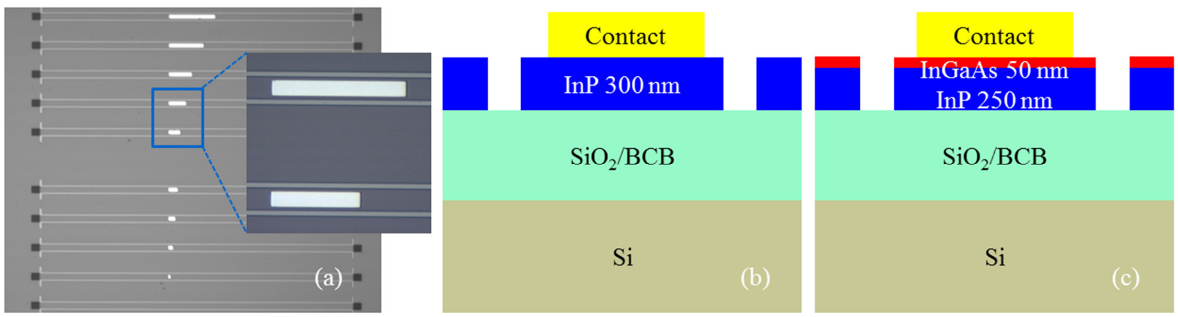

Fig. 1. (a) Image of an array of fabricated membrane WGs with metal contacts on top. (b) Cross-section of the InP WG. (c) Cross-section of the InGaAs/InP WG. The InGaAs layer is n-type doped to 2×10^{19} cm^{-3}.

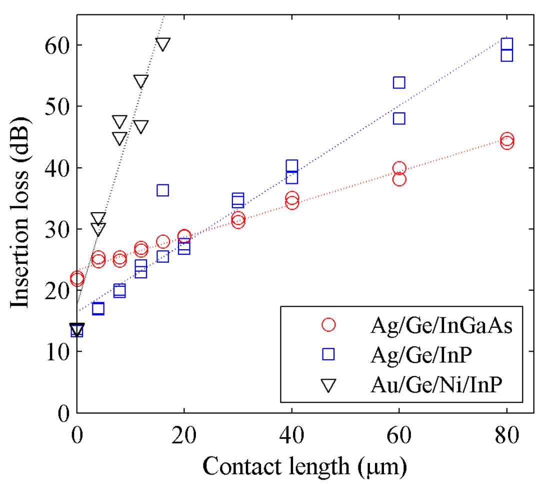

Fig. 2. Insertion loss of membrane WGs as a function of contact length measured at 1550 nm. Results with different contacts are shown. Dotted lines represent linear fits.

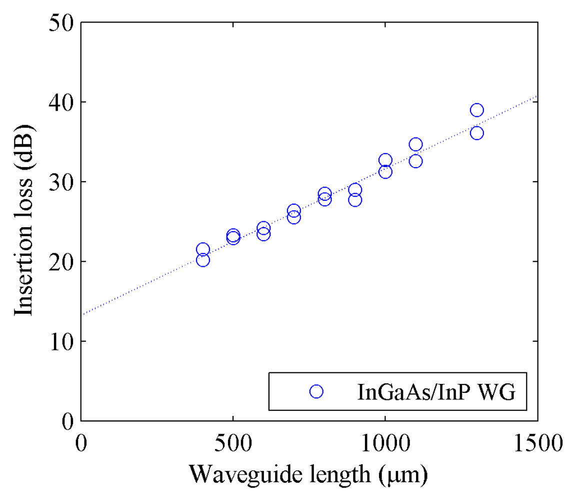

Fig. 3. Insertion loss of InGaAs/InP WGs as a function of WG length measured at 1550 nm. No metal contacts are present. Dotted lines represent linear fits

Table 2. Summarized comparison between different n-type contact technologies

Contact type	Annealing required	Specific contact resistance (Ωcm^2)	Loss coefficient (dB/µm)
Au/Ge/Ni/InP	Yes	4.0×10^{-7}	2.91
Ag/Ge/InP	Yes	1.8×10^{-6}	0.56
Ag/Ge/InGaAs	No	7.2×10^{-7}	0.27