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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[4] D. Hahn, O. Jaschinski, H. Wehmann, and A. Schlachetzki, "Electron-concentration dependence of absorption and refraction in n-$In_{0.53}Ga_{0.47}As$ near the band-edge," *J. Electron. Mater.*, vol. 24, pp. 1357-1361, 1995.

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}

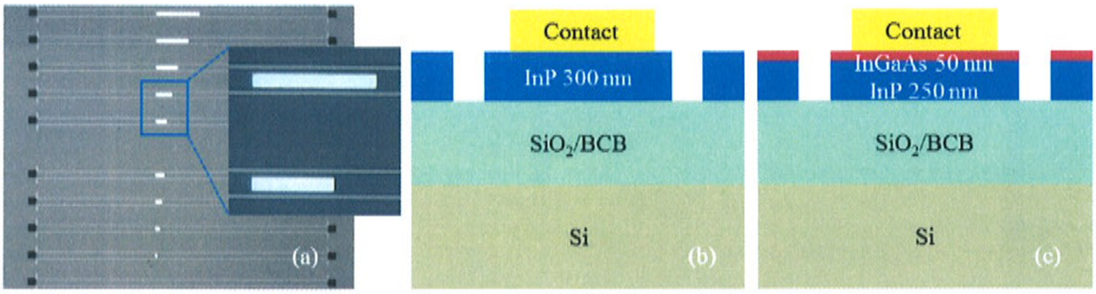

Fig. 1. (a) Image of an array of fabricated membrane WGs with metal contacts on top. (b) Cross-section of the InP WG. (c) Cross-section of the InGaAs/InP WG. The InGaAs layer is n-type doped to 2×10^{19} cm^{-3}.

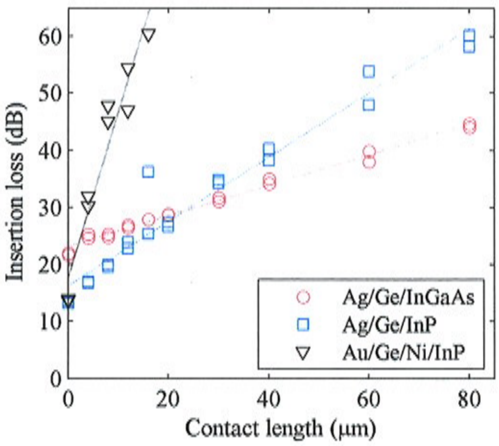

Fig. 2. Insertion loss of membrane WGs as a function of contact length measured at 1550 nm. Results with different contacts are shown. Dotted lines represent linear fits.

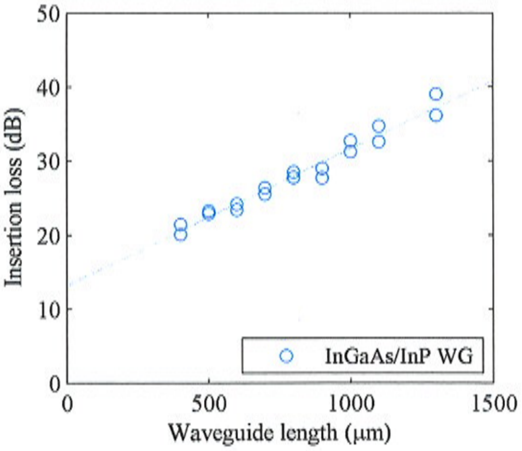

Fig. 3. Insertion loss of InGaAs/InP WGs as a function of WG length measured at 1550 nm. No metal contacts are present. Dotted lines represent linear fits

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

exhibit enhanced luminescence with a maximum quantum yield of 9.6% which is 48 times higher than that of pristine GO thin films. The achieved quantum yield in our hybrids is the highest reported so far to the best of our knowledge for GO in thin film form. Our synthesized GO nanoscrolls exhibited a length of around 20 μm and nanoscale interior cavities.

Mo4PP-O.12 ***Study of Semi-Insulating Buried Heterostructure 1.3μm Electro-Absorbtion Modulated Laser***

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Monolithic PIC transmitters using novel prefixed optical phase switching concept for BPSK/QPSK modulation format have been shown promising at 1.55μm band. Thanks to their size, consumption and cost reduction, these devices could also be crucial for access, short reach and datacom networks, where they should be redesigned for operation at 1.3μm wavelength. In this aim, we are studying basic quantum well design for laser and electro-absorption modulator switch to be integrated into PICs using our Selective Area Growth platform. Optimum design for 1.3μm put new stringent requirements on this epitaxial technique. Broad area measurements have been performed and photocurrent spectra have been studied to determine the MQW stack well-fitted for this application. Demonstration of 1.55μm laser with an electro-absorption modulator have already shown 60GHz bandwith with static extinction ration of 18dB and similar results are expected at 1.3μm band.

Mo4PP-O.13 ***Low Optical Loss Ohmic Contacts on Heavily Doped N-type InGaAs for InP Membrane Devices***

Longfei Shen (Eindhoven University of Technology, The Netherlands)

It is of great importance for InP-membrane based photonic devices to have an n-type ohmic contact on top with both low contact resistance and low optical loss. Here we present a novel contact technology based on Ag/Ge to meet these requirements. Compared with conventional Au/Ge/Ni contacts, Ag/Ge has lower optical absorption loss in the telecommunication wavelength range. The metal spiking into InP membranes during the annealing process is also reduced in Ag/Ge contacts. Furthermore, by growing a heavily doped n-InGaAs layer on top of the InP membrane, an annealing-free ohmic contact can be formed with a very low contact resistance (below 10-6 Ω cm2). Waveguide structures are fabricated to characterize the optical properties. The heavily doped InGaAs layer introduces very limited absorption loss due to strong band-filling effects. It is shown from the measurements that the annealing-free contact leads to a large reduction of the optical propagation loss.

Mo4PP-O.14 ***Growth and Characterization of MgxZn1-xO/Ag/MgxZn1-xO Multilayer Structure as Transparent Conducting Electrode for UV Light-Emitting Diode***

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We report on the characteristics of MgxZn1-xO/Ag/MgxZn1-xO transparent conductive electrodes with various Ag thickness and Mg composition in MgxZn1-xO layer. The transmittance and sheet resistance of MgxZn1-xO/Ag/MgxZn1-xO deposited at room temperature strongly depend on the thickness of Ag layer. The optical absorption edge of MgxZn1-xO/Ag/MgxZn1-xO showed a blue shift with increasing Mg composition due to increasing of band gap of MgxZn1-xO. The Mg0.28Zn0.72O/Ag/Mg0.28Zn0.72O/ITO (10 nm) and ITO (150 nm) were deposited on p-GaN as a transparent conductive layer of UV LED with an emission wavelength of 380 nm. Light output power was improved by 49% and 41% at 20 mA and 100 mA, respectively. The enhanced light output power of UV LEDs with Mg0.28Zn0.72O/Ag/Mg0.28Zn0.72O/ITO was attributed to the high transmittance of Mg0.28Zn0.72O/Ag/Mg0.28Zn0.72O/ITO in UV wavelength region. These results indicate MgZnO-based multilayer TCL can be used as a high performance TCL in UV LEDs, touch panels, and solar cells.

Mo4PP-O.15 ***InGaN/GaN Core/Shell Nanowires for Visible to Ultraviolet Range Photodetection***

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InGaN/GaN core/shell nanowires of high crystalline perfection present numerous advantages for detection and emission of visible and ultraviolet light. Their core/shell geometry allows to growth active region in a non-polar direction and thus eliminate the internal electric field in the quantum wells. In this work, we investigate the photoresponse of nanowires with radial InGaN/GaN quantum wells for their application for visible to ultraviolet range photodetectors. The MOCVD-grown single nanowires were processed into two-terminal devices with different contact layouts. The single wire detectors were probed by photocurrent spectroscopy showing the photoresponse of several pA/W at wavelengths below 440 nm with cut-off frequencies of several hundreds of Hz. Electron beam induced current mapping demonstrates that the active region extends over the top part of the wires covered with active region. The single wire photodetectors were integrated with SiN waveguides and used to detect the light generated by single nanowire light emitting diodes.

Tuesday, June 30

Monday, June 29, 19:00 - 20:30

Mo5RS: Rump Session: Future of Innovation and Entrepreneurship in Compound Semiconductors

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