A low-resistance spiking-free n-type ohmic contact for InP membrane devices

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***Short-Abstract*—Au spiking is a long-standing problem for Ni/Ge/Au ohmic contacts on n-InP. This becomes more critical when the contacts are deposited on top of thin membrane devices. In order to reduce the spiking while maintaining a low resistance, we present a new approach which reduces the amount of Au in these contacts. A low specific contact resistance of 7×10^{-7} Ω cm^2 is obtained after a 15 s annealing at 400 °C. Afterwards the contacts can be thickened with an extra deposition of metals. Scanning electron microscope pictures show abrupt and uniform interfaces between metals and semiconductors.**

I. INTRODUCTION

InP Membrane on Silicon (IMOS) technology provides a new platform for monolithic integration of a full set of photonic devices on top of CMOS chips. These devices are fabricated in an InP-based membrane which is bonded to a silicon wafer by using polymer benzocyclobutene (BCB). Recently, a variety of passive components have been realized in this platform [1, 2] and active devices are being developed.

In contrast to conventional InP-based devices, the top contact of an IMOS device is typically n-type. This is because with Metalorganic Chemical Vapour Deposition (MOCVD) the InP wafer is usually grown from n-side to p-side to minimize the diffusion of Zn (p-type dopant). After the flip-chip bonding and substrate removal, the n-type contact is deposited on top of the active layers. In order to make ultra-small and high-performance devices, the resistance of this n-type contact has to be minimized. Furthermore, any spiking of metals into the InP membrane underneath can cause high optical loss and large leakage current, and therefore needs to be avoided.

Ni/Ge/Au-based ohmic contacts to n-InP show very low contact resistance after annealing [3, 4]. However, the thermal process also leads to poor morphology and metal spiking as a result of Au diffusion. Non-Au contacts have been tested but the resistances are typically an order of magnitude higher than those of Au-based contacts [3]. Reference [4] investigates the role of Au in driving the decomposition of a ternary Ni-In-P phase and the subsequent formation of Ni_2P. This formation is regarded to be important for the ohmic behavior due to its lower barrier height. Interestingly, a method involving a small addition of Au to the Ni/Ge contact on n-GaAs has been investigated to achieve both low resistance and uniform metal-semiconductor interface [5]. In this paper, we present a similar approach for the contact on n-InP.

II. EXPERIMENTAL PROCEDURE

The sample in the experiment is a Fe doped semi-insulating InP (100) substrate with a 100 nm thick n-InP contact layer grown by MOCVD. This n-InP layer was doped to a level of 1×10^{18} cm^{-3} with Si. Metals were deposited by electron beam evaporation. Four samples with different amount of Au in the metal contact have been processed (Figure 1). A 15 s annealing at 400 °C was performed for these samples. Afterwards extra Ti/Au (10/100 nm) was deposited on sample A, B and C to reach a sufficiently low sheet resistance of the metal layer. This is required for the measurement of the contact resistance. This scheme is typically used in membrane devices: an ohmic contact is first deposited and annealed, followed by a final metallization step to define the large-area electrodes.

A circular transfer length method (CTLM) was used to measure the specific contact resistance, because of its simplicity in terms of processing [6]. Scanning electron microscope (SEM) cross-sectional pictures were made to compare the metal-semiconductor interfaces.

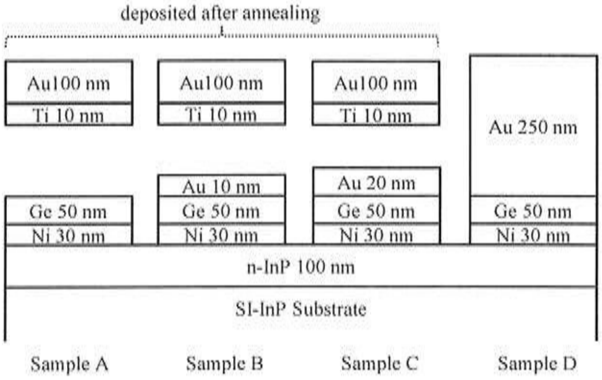

Figure 1. Schematic of contact structures

III. RESULTS

A. *Contact resistance*

From the CTLM measurements, sample A (without Au in the contact) produces specific contact resistances above 2×10^{-6} Ω cm^2, higher than the ones of the other samples with certain amounts of Au (Figure 2). This is consistent with previous observations [3, 5] and it confirms the important contribution of Au in the ohmic behavior. The conventional Ni/Ge/Au (250 nm of Au) contact in sample D shows specific contact resistances of around 4×10^{-7} Ω cm^2, which is consistent with the trend in other published results [3]. The specific contact resistances of sample B and C (10 and 20 nm of Au) show an average value of 7×10^{-7} Ω cm^2. The small increase of contact resistance is due to the very limited amounts of Au in the metal layers. To our knowledge these results are better than other non-Au contacts with the same doping level of n-InP, and are sufficiently low for our device applications.

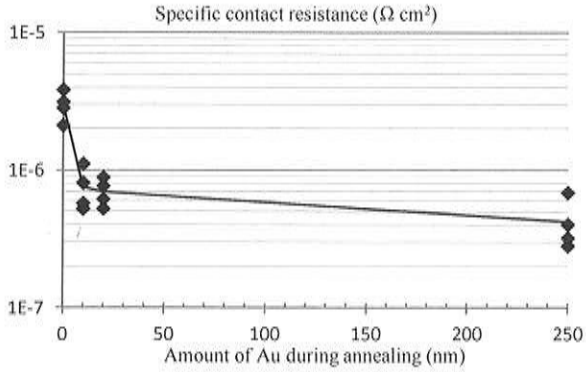

Figure 2. Measurement results of contact resistance

B. *Metal-semiconductor interface*

Figure 3 shows the SEM pictures for comparing the spiking behaviors of sample B and D. Sample D produces a very rough interface as a result of metal spiking during the high temperature annealing. The metals and alloys penetrate over 100 nm into the InP layer. In contrast, sample B shows a very sharp interface without the presence of spiking. This difference in the interface uniformity is also confirmed in focused ion beam (FIB) cut cross-section views (Figure 4), made to exclude the influence from manual cleaving. As is shown in these pictures, the alloy reactions can be limited above the interface by using only 10 nm of Au and the spiking problem is solved.

IV. CONCLUSION

In this paper we present an approach to make low resistance and spiking-free metal contacts to n-InP. By reducing the amount of Au to 10 nm, we obtained abrupt interfaces without large increase of contact resistance. Electrical measurements demonstrated a specific contact resistance as low as 7×10^{-7} Ω cm^2. This n-type contact can be used in photonic membrane devices with high speed, low loss and low leakage current.

ACKNOWLEDGMENT

We thank Nanolab@TU/e for the cleanroom facilities. L. S. thanks P.J. van Veldhoven for preparing the samples, thanks B. Barcones Campo for help in the FIB experiment, and thanks E.J. Geluk for discussions about electron beam evaporation. This work has been supported by the ERC NOLIMITS grant.

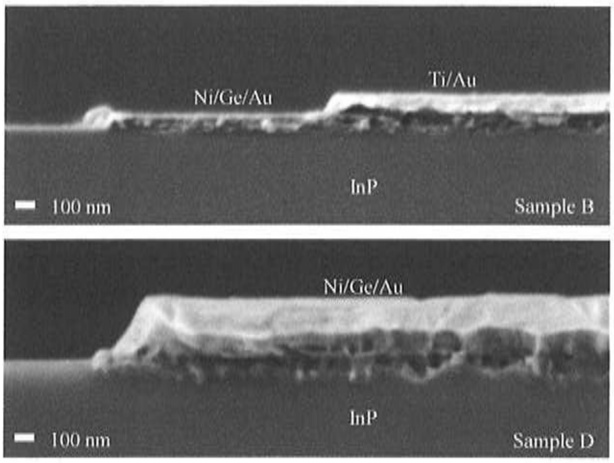

Figure 3. SEM pictures of cleaved cross-sections from Sample B and D

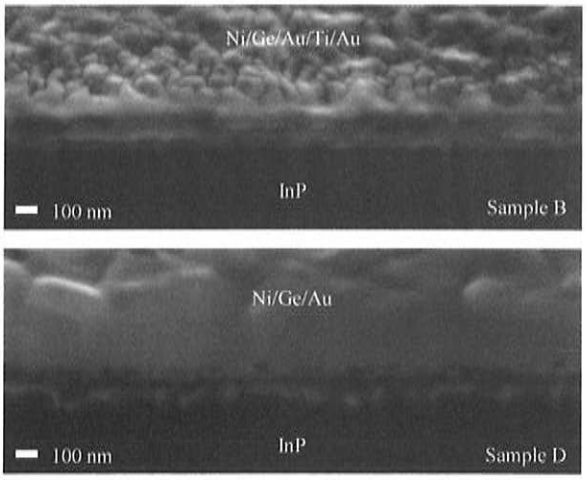

Figure 4. SEM pictures of FIB-cut cross-sections from Sample B and D

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P16

Quantum Dash based lasers for Gas Sensing

Papatryfonos Konstantinos(1), Joshi Siddarth(2), Merghem Kamel(1), Bouchoule Sophie(1), Guilet Stephan(1), Le Gratiet Luc(1), Martinez Anthony(1), Ramdane Abderrahim(1)

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We present results on InAs/InP quantum dash based broad area and ridge-waveguide lasers with emission wavelength up to 2 um. In addition a simulation-based design for laterally coupled DFB/DBR lasers is discussed, and the optimization of the processing steps for the realization of this design is presented. The design is fully compatible with readily available processing techniques and enables sufficiently high coupling coefficients for the realization of a tunable laterally coupled DBR (LC-DBR) laser, without the need of employing any regrowth steps over corrugated substrates, used for conventional DBR lasers.

P17

Modeling and Tolerance Analysis of Monolithic InP-based Dual Polarization QPSK Transmitter

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We present a detailed circuit model for a monolithic integrated InP transmitter and its application for the study of technological limitations such the impact of non-ideal phase shifters and reflections at interfaces.

P18

Detection of high THz iradiation by field effect transistors

But Dmytro(1), Sakhno Mikola(2), Oden Jonathan(3), Notake Takashi(4), Dyakonova Nina(1), Coquillat Dominique(1), Teppe Frederic(1), Minamide Hiroaki(4), Otani Chiko(4), Knap Wojciech(1)

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4 - Tera-Photonics Lab., RIKEN (Japan)

Terahertz power dependence of the photoresponse of field effect transistors, operating at frequencies from 0.1 to 3 THz for incident radiation power density up to 100 kW/cm^2 was studied InGaAs high electron mobility transistors. The observed signal saturation behavior is explained by analogy with current saturation in standard direct currents output characteristics. The theoretical model of terahertz field effect transistor photoresponse was developed shows a good description match with experimental data. Our experimental results show that dynamic range of field effect transistors based terahertz detectors is very high and can extend from mW/cm^2 up to kW/cm^2.

P19

Spectral and temporal phase measurement by Optical Frequency-Domain Reflectometry

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In the present work, we report on the spectral and temporal phase measurement capabilities of OFDR. Precise characterization of spectral phase information is demonstrated by retrieving the phase response of a commercial optical filter, the Finisar Waveshaper 1000 S/X, programmable in attenuation and phase over C+L band (1530-1625nm). Additionally, we demonstrate the high sensitivity of the technique to Doppler effects, enabling the use of OFDR for the characterization of dynamical aspects of optoelectronic components.

P20

Concept of two photon photodetector based on interband and intersubband transitions in GaInAs/AlAsSb quantum wells

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We propose an efficient two photon photodetector concept based on both interband and intersubband transition using InGaAs/AlAsSb quantum wells on InP substrate. The enhanced two-photon response is expected to arise from the use of resonant transition and differential barrier tunneling/thermionic emission rates in the conduction band. We present first experimental results on a preliminary pin photodiode containing 7 quantum wells with an absorption threshold at 1.55µm through photocurrent analysis.

P21

Substrate bonding using electroplated copper through silicon vias for VCSEL fabrication

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We present a novel approach to bound any substrate on a silicon host platform, in the particular case of the realization of InP based vertical cavity surface emitting lasers (VCSEL). This process is based on a mechanical bonding, using electroplated copper through silicon vias. It enables a cost effective bonding with a low induced stress, and a significant improvement of the device thermal properties. Preliminary results are presented on the realization of light emitting diodes.

P22

A low-resistance spiking-free n-type ohmic contact for InP membrane devices

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2 - SMART Photonics (Netherlands),

3 - Photonics Research Group - INTEC - Ghent University - IMEC (Belgium)

Au spiking is a long-standing problem for Ni/Ge/Au ohmic contacts on n-InP. This becomes more critical when the contacts are deposited on top of thin membrane devices. In order to reduce the spiking while maintaining a low resistance, we present a new approach which reduces the amount of Au in these contacts. A low specific contact resistance of 7*10-7 Ohm cm2 is obtained after a 15 s annealing at 400 ºC. Afterwards the contacts can be thickened with an extra deposition of metals. Scanning electron microscope pictures show abrupt and uniform interfaces between metals and semiconductors.

P23

Electrical injection in GaP-based laser waveguides and active areas

Gauthier Jean-Philippe(1), Robert Cedric(1), Almosni Samy(1), Cornet Charles(1), Leger Yoan(1), Perrin Mathieu(1), Letoublon Antoine(1), Levallois Christophe(1), Paranthoen Cyril(1), Burin Jean-Philippe(1), Even Jacky(1), Rohel Tony(1), Tavernier Karine(1), Le Pouliquen Julie(1), Marie Xavier(2), Carrere Helene(2), Balocchi Andrea(2), Durand Olivier(1)

1 - Fonctions Optiques pour les Technologies de l'informatiON (France),

2 - Institut national Des Sciences Appliquees de Toulouse (France)

This paper presents the recent advances in device engineering towards the fabrication of an electrically pumped laser on gallium phosphide (GaP) substrate for photonic integration on silicon. The letter first presents the electrical properties of a GaP-based PIN diode, in particular the reduction of the characteristic resistance of the p-contact, thanks to a judicious combination of metal choice and thermal annealing. Secondly, carrier injection in the active area is investigated by use of time-resolved photoluminescence, regarding particularly the nature and composition of the barrier and quantum wells materials, with a focus on the nitrogen incorporation issues.

Time	Sunday, 11 May	Monday, 12 May			
8h30		Opening			
9h		Plenary 1			
9h30		Plenary 2			
10h					
10h30		coffee break 10h15-10h45			
11h		Plenary 3			
11h30		Plenary 4			
12h					
12h30		Lunch - 12h30-13h30h			
13h					
13h30	Room C Short course A	Mo-A1 ISCS	Mo-B1 IPRM	Mo-C1 IPRM	Mo-D1 ISCS
14h		GaN Prospective	Phot. Integ.1	Elec. Dev.1	NW Growth
14h30					
15h	Break	coffee break 15h-15h30			
15h30	Room C Short course B	Mo-A2 IPRM	Mo-B2 IPRM	Mo-C2 ISCS	Mo-D2 ISCS
16h		Epi.-Nano. 1	Opto.1	Oxydes - Electro. Opt.	Carbon-flexible
16h30					
17h	CSW Registration	Poster session/beers/wines -17h-19h			
17h30					
18h	Welcome Reception				
18h30					
19h					
19h30					

Time	Tuesday, 13 May			
8h30	Tu-A1 ISCS		Tu-C1 ISCS	Tu-D1 ISCS
9h		Tu-B1 IPRM		
9h30	Solar	Elec. Dev2	Oxydes	Epi. & Mat for advanced devices
10h				
10h30	coffee break 10h30-11h			
11h	Tu-A2 ISCS	Tu-B2 ISCS	Tu-C2 ISCS	Tu-D2 IPRM
11h30				
12h	GaN NW and UV	MIR-ThZ	Physics - Transport	Epi.-Nano. 2
12h30				
13h	Lunch - 13h-14h00			
13h30				
14h	Tu-A3 ISCS	Tu-B3 ISCS	Tu-C3 ISCS	Tu-D3 IPRM
14h30				
15h	Lasers	QW-QD Growth	In-based nitride mat. & dev.	Opto.2
15h30				
16h	Coffee break 15h45-16h15			
16h30	IPRM/ISCS award ceremony - 16h15-17h			
17h	Rump session 17h-19h			
17h30				
18h				
18h30				

Time	Wednesday, 14 May			
8h30	We-A1 ISCS		We-C1 ISCS	We-D1 ISCS
9h		We-B1 IPRM		
9h30	µcavities & NW-lasers	Phot. Integ.2	Physics-optics	High-Frequency
10h				
10h30	coffee break 10h30-11h			
11h	We-A2 ISCS	We-B2 ISCS	We-C2 ISCS	We-D2 IPRM
11h30				
12h	Zn based oxydes	Nanocharac	Nitrides on SI & Photon	Phot. Integ.3
12h30				
13h	Excursion 13h -18h (lunch is provided)			
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19h	Conference dinner 19h-22h			
19h30				
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Time	Thursday, 15 May			
8h30				
9h	Th-A1	Th-B1 IPRM	Th-C1 ISCS	Th-D1 ISCS
9h30	Post-deadline	Epi.-Nano.3	N-based devices 1	Photo detector
10h				
10h30	coffee break 10h30-11h			
11h	Th-A2 ISCS	Th-B2 IPRM	Th-C2	Th-D2 IPRM
11h30				
12h	N-based devices 2	Opto.3	Post-deadline	Elec. Dev.3
12h30				
13h	Closing and Student Award ceremony 12h45-13h15			
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Compound Semiconductor Week - 11th - 15th May 2014 - Le Corum - Montpellier - FRANCE

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2ÈME DE COUVERTURE VIERGE

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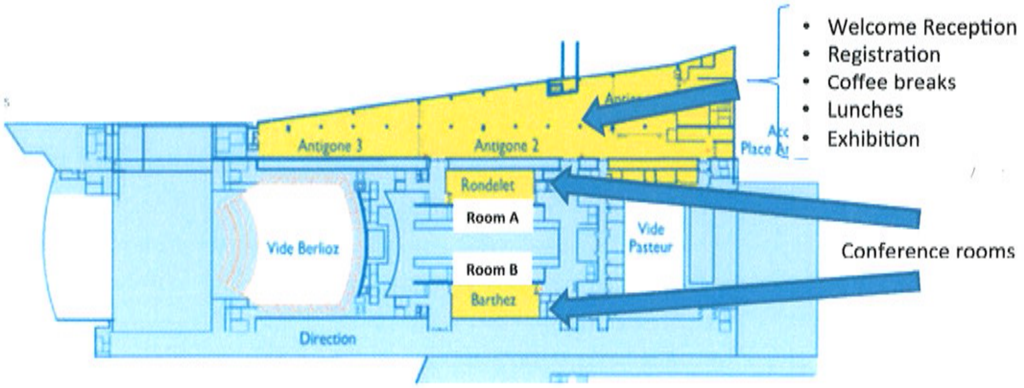
NIVEAU 2
LEVEL 2



- Welcome Reception
- Registration
- Coffee breaks
- Lunches
- Exhibition

LE CORUM
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NIVEAU 1
LEVEL 1