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 7.5×10⁻⁵ Ω cm² is obtained after a 15 s annealing at 400 °C. Afterwards the contacts can be thinned 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 Ni₅P. 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 NiGe 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 1×10¹⁸ 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](image_url)

III. RESULTS

A. Contact resistance

From the CTLM measurements, sample A (without Au in the contact) produces specific contact resistances above 2×10⁻⁵ Ω cm², 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 $4 \times 10^{-7} \Omega \text{cm}^2$, 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 $7 \times 10^{-7} \Omega \text{cm}^2$. 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 limited doping level of n-InP, and are sufficiently low for our device applications.

![Graph showing specific contact resistance vs. amount of Au](image)

**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.

![SEM pictures of cleaved cross-sections from Sample B and D](image)

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

![SEM pictures of FIB-cut cross-sections from Sample B and D](image)

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

### 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 $7 \times 10^{-7} \Omega \text{cm}^2$. 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. Barones Camilo for help in the FIB experiment, and thanks E.J. Gellert for discussions about electron beam evaporation. This work has been supported by the ERC NOLIMITS grant.

### REFERENCES


IPM-Optoelectronics and related technologies

P16 Quantum Dash based lasers for Gas Sensing

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We present results we have on a quantum dash based broad area and ridge waveguide lasers with emission wavelength up to 2 μm. In addition a simulation based design for laterally coupled DFB/DBR lasers is described, 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 DFB/DBR laser, without the need of employing any regrowth steps over corrugated substrates, used for conventional DFB lasers.

P17 Modeling and Tolerance Analysis of Monolithic InP-based Dual Polarisation 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 radiation by field effect transistors

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Terahertz power dependence of the photocurrent of metal field effect transistors, operating at frequencies from 0.5 to 3 THz for incident radiation power density up to 100 mW/cm² was studied InGaAs high electron mobility transistors. The observed signal saturation behavior is explained by analogy with current saturation in standard direct current output characteristics. The theoretical model of terahertz field effect inductor photocurrent was developed shows a good description match with experimental data. Our experimental results show that dynamic range of high field effect transistors based detectors is very high and can extend from mW/cm² up to kW/cm².

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 characterisation of spectral phase information is demonstrated by retrieving the phase response of a commercial optical filter, the Novanta Wavemaker 1000 YS, programmable in attenuation and phase over a C+L band (1530-1565 nm). 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/InAs quantum wells

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

P21 Substrate bonding using electroplated copper through silicon via for VCSEL fabrication

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We present a novel approach to bond 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 via. 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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Au spiking is a long-standing problem for Ni/GexAu ohmic contacts on 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 0.05Ω-mm cm is achieved after a 15 s annealing at 500°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.

P23 Electrical injection in GaP-based laser waveguides and active areas

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This paper presents the recent advances in device engineering towards the fabrication of an electrically pumped laser on gallium phosphide (GaP) substrate for the photonic integration on silicon. The letter first presents the electrical properties of a GaP-based Pd 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 well materials, with a focus on the nitrogen incorporation issues.