4.2.6 Investigation and Processing of Ohmic Contacts on Highly Doped n-InGaAs

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Introduction
Ohmic contacts are very important for improving the functionality and the reliability of semiconductor devices. InP-based InGaAs/AlAs double barrier resonant tunneling diode needs low ohmic contact resistance to keep the voltage drop low and to achieve high frequency performance, especially for devices with high current density [1]. The metal combination Ti/Pt/Au is currently used for ohmic contact realization on n+-InGaAs in the Solid State Electronic departement.

Palladium featured as an alternative to replace Pt. Both are group VIII transition metals, and therefore should not differ significantly in chemical and physical properties (similar resistivity and work function Pd: 9.93 µΩ cm; 4.99 eV und Pt: 9.85 µΩ cm; 5.32 eV respectively). In this experiment, palladium will be investigated to replace Pt as the contact metal for highly doped n-InGaAs layer. The electrical characterization of fabricated ohmic contact is carried out by using the well known transmission line measurement (TLM) and the newly developed in III-V semiconductor cross-bridge Kelvin resistor (CBKR).

Technology
The experimented InGaAs-samples, which were lattice matched grown with doping concentration of $1 \times 10^{-19} \text{cm}^{-3}$ by molecular beam epitaxy on a semi-insulating InP-substrate, were structured by optical lithography, wet etching and metalized by evaporation deposition and lift-off techniques. The desired contact metals were deposited via electron beam evaporation or thermal evaporation for Ti; Pt or for Pd; Au respectively, however the thermal evaporation of Pd was improved after a vacuum rupture in another evaporation system. To remove the surface native oxide prior to metallization, the samples were cleaned in a solution with 10% ammonium hydroxide (NH$_4$OH) after photoresist developing. After the metalization and the lift-off process, the wet chemical etching was carried out with the mixture of phosphoric acid with hydrogen peroxide and water (1:1:25/ H$_3$PO$_4$:H$_2$O$_2$:H$_2$O), which is highly selective for InGaAs with aspect to InP-substrate [3]. To fabricate the CBKR with only two lithography steps, the metals connection between upper contact and contact pad of CBKR were slim designed in order to realize an air-bridges with the wet-underetching (fig. 1-b). The contacts on highly doped n+-InGaAs-samples were made with 10 nm Titanium, 10 nm Palladium, 400 nm Gold metal system and 20 nm Titanium, 20 nm Palladium, /400 nm Gold metal system.

Measurement principle of cross-bridge Kelvin resistor
The measurement principle of CBKR structure consists of forcing the current flow ($I$) from metal side to semiconductor side and measuring with the connected voltmeter the voltage drop ($V_{t}-V_{2}$) at
the contact interface (fig. 1-a). The measured contact resistance $R_c$ can then be calculated as:

$$R_c = \frac{V_4 - V_2}{I}$$

![Fig. 1](image)

(a) functional diagram of CBKR (b) SEM micrograph of realized cross bridge Kelvin resistor: For a better limitation of the active contact area the undercuts under thin metals produce metal air bridges.

The specific contact resistance can be calculated as product of contact area $A$ and contact resistance, $\rho_c = R_c \times A$.

### Experimental Results

![Fig. 2](image)

Mapping of Specific contact resistance measured from TLM (left) and CBKR (right) structure respectively.
For TLM structures, except the cells on the edge, the variations among the specific contact resistances are in a small range. For CBKR, though specific contact resistances are smaller and their value variations are bigger. The CBKR structures are sensitive to the local surface states due to random doping fluctuations and other impurities, because of their small contact size. The specific contact resistances for CBKR and TLM structures are proportional, but the CBKR results are lower. CBKR can be used to quantify the local variations and can also be easily integrated.

![Specific contact resistances of TLM structures with Ti/Pd/Au contacts vs. the annealing time](image)

**Fig. 3  Specific contact resistances of TLM structures with Ti/Pd/Au contacts vs. the annealing time**

Ti/Pd/Au is non-alloyed ohmic contact and shows a good ohmic characteristic on highly doped n⁺-InGaAs before and after annealing. The optimum annealing parameter for the contacts is found at T = 300 °C and t = 20 s for 10 nm/10 nm/400 nm Ti/Pd/Au resulting in a specific contact resistance of $9.12 \times 10^{-8} \, \Omega \cdot \text{cm}^2$ for TLM structure. The reference sample with 20 nm Ti/20 nm Pt/400 nm Au contact shows a specific contact resistance of $2.21 \times 10^{-7} \, \Omega \cdot \text{cm}^2$ after his optimum annealing process (T=360 °C @ 10 s). The optimized ohmic contact with Palladium has lower specific contact resistance than the reference sample (Ti/Pt/Au). In addition, the evaporation process of Palladium is flexible.

**Conclusion**

In this work Palladium has been investigated for contacts to n-doped InGaAs in InP-based devices to replace Platinum and has the best ohmic contact property. A specific contact resistance of $9.12 \times 10^{-8} \, \Omega \cdot \text{cm}^2$ was obtained with Ti/Pd/Au. Future works will focus on the understanding of the difference between the results obtained by both measurement methods (TLM and CBKR).
References

