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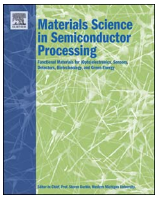

Study on the specific contact resistance of evaporated or electroplated golden contacts to *n*- and *p*- type InAs epitaxial layers grown by MBE

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ABSTRACT

The specific contact resistance of golden contacts made by electroplating or evaporation for *p*-type InAs:Be and *n*-type InAs:Si epitaxial layers grown by MBE was studied. The Circular Transmission Line Model (CTLM) was applied to determine the specific contact resistance. The measured specific contact resistances were correlated with metallization method and Hall concentration of holes and electrons. The lowest resistances were obtained for highly Be and Si doped layers. It was shown that high quality low resistance contacts can be obtained by gold electroplating, especially for highly Be and Si doped InAs layers.

1. Introduction

Contact deposition is one of the most important stages of semiconductor device *processing* in fabrication of IR detectors. The parasitic resistance of electrical contacts affects performance of the devices and should be minimized. Vacuum evaporation of gold is a commonly used method of metallization in semiconductor *processing* [1]. This method is time consuming and requires costly equipment. In this work, we propose to use cost- and time- efficient galvanic gold deposition [2,3]. The main aim of this work is to compare quality of Au/InAs contacts, prepared with the two techniques.

The specific contact resistance ρ_c (in $\Omega\,\mathrm{cm}^2$) is a normalized contact resistance, which can be used to compare contacts of various area and shape [1]. A proper test procedure and a suitable model are required to determine correctly the ρ_c, especially since the current density distribution is usually inhomogeneous because of a decrease of voltage in the semiconductor. This effect is known as the current crowding effect (CCE) [4].

The CTLM given by the following equation was applied in this work [5–8]:

$$R = \frac{R_{SH}}{2\pi}\left[\frac{L_T}{L}\frac{I_0\,(L/L_T)}{I_1\,(L/L_T)} + \frac{L_T}{L+d}\times\frac{K_0\,(L/L_T)}{K_1\,(L/L_T)} + ln\left(1+\frac{d}{L}\right)\right] \tag{1}$$

where: R - measured contact resistance at 0 V bias, R_{SH} - sheet resistance, L - contact area radius, I; K - modified first order Bessel's functions, d - width of area without metallization, L_T - current penetration depth. The L_T is related to the distance at which the majority of current flows from a semiconductor to metallic contact or reverse and is given by:

$$L_T = \sqrt{\frac{\rho_c}{R_{SH}}} \tag{2}$$

Assuming $L > 4L_T$ and the same R_{SH} of a semiconductor with and without metallization, the quotients of modified first order Bessel's functions tend to one. In view of the above, the relation simplifies to the following form:

$$R = \frac{R_{SH}}{2\pi}\left[\frac{L_T}{L} + \frac{L_T}{L+d} + ln\left(1+\frac{d}{L}\right)\right] \tag{3}$$

This Eq. (3) was applied in this work to determine the ρ_c by the correlation of measured R versus area radius L. Next, the ρ_c values were confronted with Hall concentrations of electrons (n_e) and holes (n_h) for two metallization methods, evaporation and electroplating.

The CTLM method has an advantage over other methods like TLM in which the rectangular contact patterns are used. In the case of circular contacts there are no necessity to insulate contact area by etching a mesa structure to provide current flow directly from contact area to common contact [1,9,10]. That was the reason of CTLM method application in this work.

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Table 1
Electrical parameters of InAs layers.

Layer	Type	R_{SH}, Ω / sq (300 K)	n_h, cm^{-3}	n_e, cm^{-3}
1	*p*	584.07	4.65×10^{17}	–
2	*p*	202.17	1.74×10^{18}	–
3	*p*	97.01	1.84×10^{18}	–
4	*n*	110.61	–	2.01×10^{16}
5	*n*	8.54	–	2.20×10^{17}
6	*n*	1.69	–	3.04×10^{18}
7	*n (nid)*	152.14	–	1.57×10^{16}
8	*n (nid)*	124.37	–	1.43×10^{16}

2. Experiment

The InAs layers were grown by RIBER Compact 21-DZ solid source molecular beam epitaxy (MBE) system on 2" diameter and 0.4 mm thick GaAs semi-insulating substrates. The system was equipped with the standard and valved cracker effusion cells for In, Be, Si and As respectively. At the first stage of each growth, an approx. 0.25 µm thin GaAs layer was grown to improve a substrate surface morphology after degasing process. The growth conditions and layers parameters are collected in Tables 1 and 2.

The Hall concentration measurements were carried out by ECOPIA Hall Measurement System using Van der Pauw method as the temperature function in a range of 80–300 K with a step of 5 K under 5 mA current and 0.542 T constant magnetic field.

Photolithography was applied to delineate structures with five circular contact areas with different diameters using the AZ 4533 photoresist and NaOH solution developer (Fig. 1). At least four structures were made at the approx. 2 cm^2 area of the InAs samples.

Each sample was etched for 10 s before metallization in the mixture of orthophosphoric acid: citric acid: hydrogen peroxide: water (molar ratio: 1:1:4:16) solution and 0.4 mol/dm^3 hydrochloric acid water solution to get rid of oxides impurities from the surface [11]. The volume ratio of these solutions was 6:0.1 respectively.

Vacuum evaporation and electroplating were applied to deposit Au contacts. Evaporation was carried out at $< 3 \times 10^{-6}$ mbar in Angstrom Engineering Nexdep apparatus equipped with the dry vacuum pumps set and e-beam source. The 5 nm Ti layer was evaporated first to improve the gold adhesion. Finally the 150 nm golden contact layer was evaporated.

Electroplating was conducted in the 1.2% (w/w) $KAu(CN)_2$ water solution for 15 min using the Au anode. The electroplating process was carried out under 350–375 µA/cm^2 current density. Approx. 600 nm thick gold layer was deposited by this method. Rinsing or lift-off process using an acetone and drying by nitrogen flow was applied after electroplating and evaporation respectively to remove the photoresist. Evaporated as well as electroplated contacts passed successfully the scotch tape test, which proved good adhesion of gold to the InAs layer.

Table 2
Growth conditions of InAs layers.

Layer		Thickness, µm	V/III flux ratio	Temperature of cell, °C								Growth rate, µm/h	Temp. of manipu-lator, °C
				Ga		As		In		Be	Si		
				Tip	Base	Cracker	Reservoir	Tip	Base				
1	**GaAs**	0.25	8.1	1000	902	600	370	–	–	–	–	1.00	655
	InAs	2.10	14.1	–	–	600	370	905	763	780	–	0.75	400
2	**GaAs**	0.23	11.7	1000	912	600	370	–	–	–	–	0.92	640
	InAs	1.00	7.8	–	–	600	370	880	729	830	–	0.27	385
3	**GaAs**	0.25	8.3	1000	894	600	370	–	–	–	–	1.00	655
	InAs	2.00	12.2	–	–	600	370	905	753	860	–	0.75	400
4	**GaAs**	0.25	8.1	1000	893	600	370	–	–	–	–	1.00	655
	InAs	2.00	12.1	–	–	600	370	905	748	–	1050	0.76	400
5	**GaAs**	0.25	8.1	1000	894	600	370	–	–	–	–	1.00	655
	InAs	1.92	11.8	–	–	600	370	905	753	–	1150	0.77	400
6	**GaAs**	0.23	11.6	1000	900	600	370	–	–	–	–	0.92	640
	InAs	1.92	8.4	–	–	600	370	880	722	–	1200	0.26	355
7	**GaAs**	0.25	8.1	1000	897	900	377	–	–	–	–	1.00	655
	InAs	2.30	9.7	–	–	900	377	905	728	–	–	0.82	400
8	**GaAs**	0.25	8.1	1000	889	600	370	–	–	–	–	1.00	655
	InAs	2.74	7.4	–	–	600	370	905	748	–	–	1.02	400

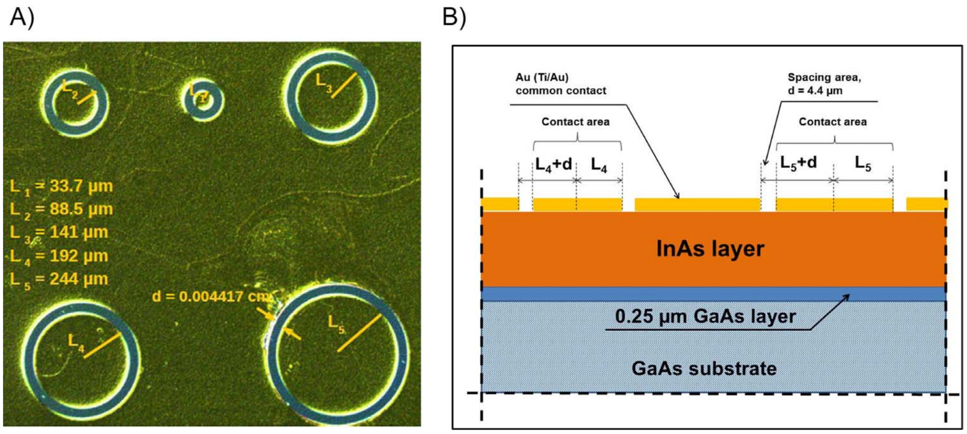

Fig. 1. A) The single photolithography structure of 5 contact areas with different radius after metallization process; B) schematic cross-section of InAs layer.