Decreasing Contact Resistance to n-InGaAs with ALD TiN

Brian Markman
Materials Science and Engineering, The Pennsylvania State University

NNIN REU Site: UCSB Nanofabrication Facility, University of California, Santa Barbara, CA
NNIN REU Principal Investigator: Dr. Mark Rodwell, Electrical and Computer Engineering, University of California, Santa Barbara
NNIN REU Mentor: Prateek Choudhary, University of California, Santa Barbara
Contact: brian.markman8@gmail.com, mjwrodwell@gmail.com, prateek.pc@gmail.com

Abstract:

The effects of multiple deposition parameters on the plasma enhanced atomic layer deposition (PEALD) of conductive titanium nitride (TiN) films were investigated. Specifically, effects of chamber pressure and plasma exposure time on TiN resistivity were characterized. Optimum growth conditions for minimum film resistivity was determined to be: substrate temperature of 300°C, plasma power of 500W, precursor gas of ammonia (NH_3), chamber pressure of 2 mTorr, and a plasma time of 30 seconds. The minimum achieved resistivity was found to be 176 $\mu\Omega$*cm.

Precursor Gases	Flow Rate (sccm)	ICP Power (W)	Resistivity (µΩ*cm)
N_2/H_2	13/39	400	814
N_2/H_2	13/39	500	453
NH_3	40	400	595
NH_3	40	500	432

Table I: Resistivity relationship to plasma power for two different plasma compositions.

Precursor Gases	Flow Rates (sccm)	Resistivity (µΩ*cm)
N_2/H_2	13/39	453
N_2/H_2	31/21	508
N_2/H_2	4/48	534
NH_3	40	340
NH_3/N_2	40/20	609

Table II: Resistivity relation to plasma composition for combinations of N_2, H_2, and NH_3.

Introduction:

Dimensional scaling of heterojunction bipolar transistors (HBT) must be supplemented by reductions in contact resistance at the emitter and base contacts, in order to improve device performance. Specifically, the emitter contact is particularly difficult to fabricate due to the extremely high aspect ratio and high current densities required. Due to these requirements, titanium nitride is of interest because of its low resistivity and high melting temperature [1, 2]. Many deposition techniques of TiN have been explored; atomic layer deposition (ALD) is of particular interest because of its conformal coating of high aspect ratio structures and low resistivity [1, 3].

Though multiple precursors are commonly used in ALD TiN deposition, tetrakis-dimethylamido titanium (TDMAT) is attractive due to its ability to deposit at temperatures below 400°C without generating chemically aggressive, non-volatile products [1, 4, 5]. Additionally, plasma assisted processes are common due to their ability to increase deposition rate and reduce resistivity [1]. This study presents a novel investigation of chamber pressure on TiN film resistivity for low contact resistance applications as well as a review of plasma power, plasma composition, plasma exposure time, and the introduction of a hold step.

Experimental Procedure:

The ALD system used in all tests was an Oxford FlexAL remote plasma system. Substrates were prepared from doped silicon <100> wafers that were coated with an insulating layer. All samples were solvent cleaned and dehydrated before being loaded into the ALD. Sigma Aldrich 99.999% TDMAT was used. An inductively coupled plasma (ICP) system was used and operated at 500W and 13.56 MHz, unless otherwise mentioned. Substrate temperature was kept at 300°C and the TDMAT bubbler was kept at 60°C.

During tests, plasma parameters including plasma power, plasma composition, chamber pressure, and plasma exposure time were varied. Sheet resistance was then measured using a four-point probe. Film thicknesses were determined using SEM and ellipsometry.

Results and Conclusions:

To achieve the lowest TiN resistivity, the effects of plasma power, plasma composition, chamber pressure, plasma exposure time, and hold step duration were investigated.

Plasma Power. As demonstrated in Table I, as plasma power is increased, the resistivity decreases independent of the precursor oxidant.

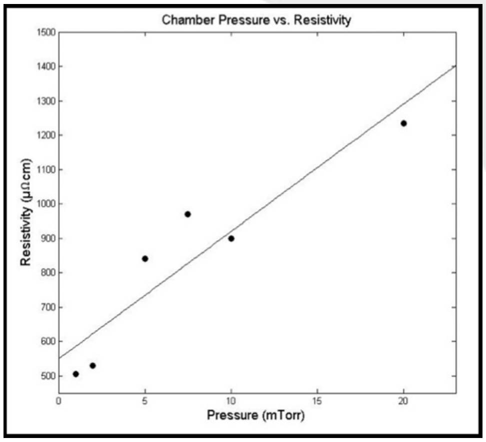

Figure 1: Resistivity as a function of chamber pressure for substrate temperature 300°C, plasma power 500W, and plasma exposure time 25 s.

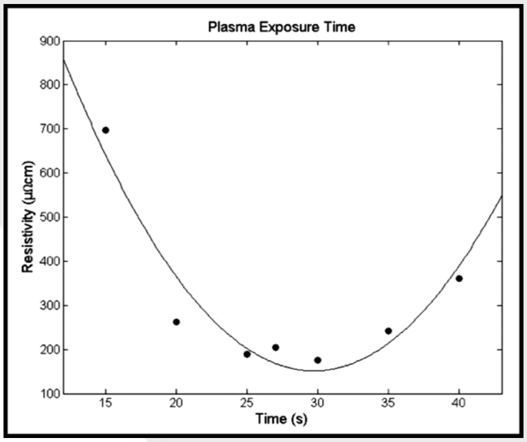

Figure 2: Resistivity as a function of plasma exposure time for substrate temperature 300°C, plasma power 500W, and chamber pressure 2 mTorr.

Plasma Composition. Both nitrogen rich and hydrogen rich plasma compositions were tested and the results are outlined in Table II. It was found that a stoichiometric ratio of N:H 1:3 is optimal for both NH_3 and N_2/H_2 precursors where NH_3 is the most favorable. This is likely due to the formation of more NH_x radicals in a NH_3 plasma than in an N_2/H_2 plasma [1, 3].

Chamber Pressure. As illustrated in Figure 1, as chamber pressure decreases, resistivity decreases. This is likely because of reduced plasma damage over time.

Plasma Time. Increasing plasma time for t < 30 seconds decreases the resistivity; however, when t > 30 seconds, resistivity increases quickly. Figure 2 demonstrates this relationship and suggests that for t < 30 seconds, the plasma is mostly reacting away the organic ligands contained within TDMAT. Likely after 30 seconds most of the ligands have been removed and subsequent plasma action results in plasma damage rather than defect removal.

Dose and Hold. The effect of introducing a hold step during the TDMAT dose was investigated. TDMAT was held in the chamber, allowing conformal coating of high aspect ratio structures. Further decomposition of the TDMAT also provided lower resistivity. A five second hold time was found to allow for the lowest resistivity, while an increased time realized no further improvements.

By increasing plasma power, using NH_3 as an oxidant, decreasing chamber pressure, and increasing plasma time (t = 30 seconds), it is possible to significantly reduce TiN film resistivity and thus create less resistive metal contacts in many devices thus enabling next generation HBTs without having to alter the base contact as well.

Future Work:

Experimentally determined TiN has recently been incorporated into 64 nm HBTs, which are currently being processed. Transmission line models (TLM) will be fabricated to quantitatively determine the contact resistance associated with the newly developed TiN recipe. The effects of plasma power on contact resistance will be examined.

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References:

[1] E. Gerritsen, et al., SSE, 49, (2005).

[2] J. K. Huang, et al., Thin Solid Films, 519, (2011).

[3] Y. Y. Chen, et al., Microelectronic Engineering, 112, (2013).

[4] P. Caubet, et al., ECS, 155, (2008).

[5] Atomic Layer Deposition, NNIN, UCSB.