Contact chain measurements for ultrathin conducting films

A.W. Groenland, R.A.M. Wolters, A.Y. Kovalgin, and J. Schmitz

***Abstract*— Test structures for the electrical characterization of ultrathin conductive (ALD) films are presented based on electrodes on which the ultrathin film is deposited. The contact resistance of the buried electrodes to the ultrathin ALD TiN films is investigated using contact chain structures. This work includes test structure design and fabrication, and the electrical characterization of ALD TiN films down to 4 nm in thickness. It is shown that contact chain structures with buried electrodes can be used successfully to characterize the contact resistance to sub 10 nm ALD TiN films.**

***Index Terms*— Titanium Nitride, Contact resistance, Test structure, Atomic Layer Deposition**

I. Introduction

TITANIUM Nitride (TiN) is a metal nitride known for its high thermodynamic stability, high corrosion resistance, low friction constant, low electrical resistivity, and high mechanical hardness. It has found application in IC technology as for example diffusion barrier [1], antireflective coating [2], gate material [3] and current conductor [4]. In MEMS, TiN is used as a heater in micro hotplates [5]. TiN can be deposited via a variety of techniques including physical vapour deposition (PVD) [6], low pressure chemical vapour deposition (LPCVD) [7] and atomic layer deposition (ALD) [8]. The properties of the TiN films are strongly influenced by the film stoichiometry, crystallinity, morphology, and hence the deposition method.

The electrical properties of ultra-thin (i.e. < 10 nm) films are of prime importance and can be measured using the four probe method. For such thin films van der Pauw structures (vdPs) and Greek Crosses (GCs) are commonly used. However, making electrical contacts to these thin films using planar technology is extremely difficult; e.g. etching a via for the contact to such a film requires a very high selectivity. In practice, this is not possible.

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Recently, we have published on special microelectronic test structures with buried electrodes which could overcome this problem. We demonstrated a successful use of these test structures for the electrical characterization of TiN layers down to 4 nm, which were deposited by Atomic Layer Deposition [9].

In this work, the contact resistance (R_c) between the buried TiW electrodes and the ALD TiN layers is investigated using contact string test structures. For 4 or 7 nm ALD TiN layers, an average specific contact resistance smaller than 1.5 × 10^{-7} Ωcm^2 and 4.6 × 10^{-7} Ωcm^2 was found, respectively. These values are realistic for high-ohmic metal-metal contacts. Our study demonstrates the possibility to extract realistic contact resistance values to ultra-thin ALD TiN layers.

II. Experimental

A series of different contact chain devices was fabricated containing 1, 2, 4, 8, 16, 32 and 64 links (and hence 2, 4, 8, 16, 32, 64 and 128 contacts respectively). The fabrication process is described in detail elsewhere [9]. Contact chains were selected as test structure for contact resistance in favour of the commonly used Kelvin structures. Kelvin devices cannot be manufactured in this particular 'electrode first' technology; contacting the top ALD layer results in the via etch problem described earlier.

In this process, samples with 4 and 7 nm ALD TiN were manufactured. A cross-section of a single contact chain link with two contacts to the ALD TiN layer is shown in Fig 1. The schematic design with dimensions is shown in Fig. 2. In Fig. 3 the whole die with all contact chain test structures is depicted. Each contact chain is contacted with four contact pads to eliminate the influence of the ('probing') contact resistance. Fig. 4 shows a picture of a realized device, in Fig. 5 a cross-section is shown of the contact between the buried electrode and the ALD TiN layer.

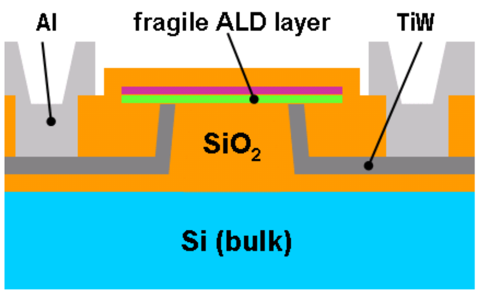


Fig. 1. Cross-section of a single link of the contact chain structure with 2 contacts.

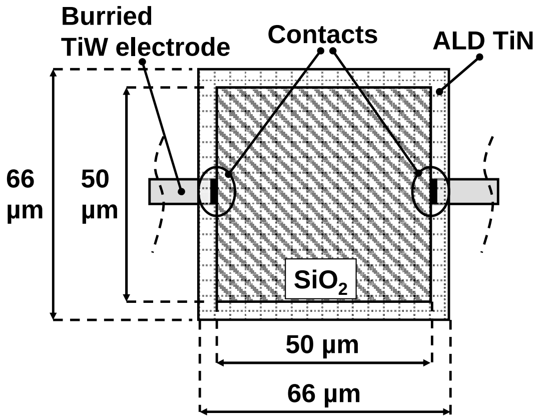


Fig. 2. Schematic design of a single link of the contact chain with two contacts to the ALD TiN layer. The area of the contacts is 2 µm × 70 nm.

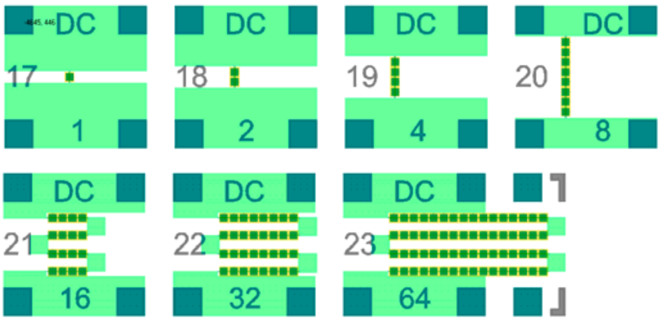
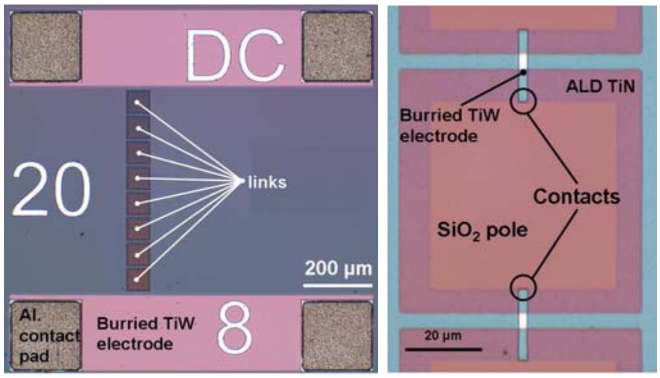


Fig. 3. Die map of all ‘daisy chain’ (DC) structures. Numbers at the bottom of each structure indicate the number of links, each link contains 2 contacts.



(a) (b)

Fig. 4. Optical micrograph of a realized contact chain structure containing 8 links (16 contacts). Whole structure (a) and close up of a single link (b).

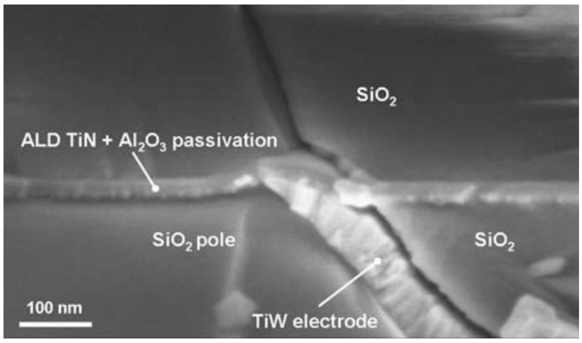


Fig. 5. HR-SEM cross-section of the contact of the buried electrode and the ALD TiN thin film. The ALD TiN film is passivated by aluminum oxide (Al_2O_3) and SiO_2.

III. Results and Discussion

For a 4 and 7 nm ALD TiN layer, *IV*-curves were measured on contact chain structures at room temperature using a HP4156B or Keithley 4200 semiconductor parameter analyser in combination with a Cascade Microtech probe station. From the slope of the *IV*-curves the measured resistance (R_m) is extracted and shown in Fig. 6 versus the number of contacts. For both TiN layers, R_m linearly scales with the number of contacts.

For each contact chain structure, R_m can be expressed as the sum of the interconnect resistance of the TiW electrodes (R_{int}), the TiN resistance (R_{TiN}) and the resistance per contact (R_c).

R_{int} is determined by calculating the number of interconnect squares for each device and multiplying it by the square resistance ($R_\square$) of TiW. The number of interconnect squares is determined for each device individually from optical microscope measurements. The square resistance of TiW is determined from Greek Cross measurements and found to be 7,87 Ω/□ and 7,44 Ω/□ for the 4 and 7 nm ALD TiN samples respectively.

The TiN resistance is determined in a similar way to R_{int}; the $R_\square$ of TiN is determined from Greek Cross measurement and found to be 720 Ω/□ and 159 Ω/□ for the 4 and 7 nm ALD TiN samples respectively. Each link is assumed to be 1 square. Subtracting R_{int} and R_{TiN} from both sets of R_m data yields R_c, the resistance per contact which is shown in Fig. 7 versus the number of contacts. Ignoring the parasitic resistance due to current crowding in the ALD TiN thin film [10], the multiplication of R_c and the contact area (2 µm × 70 nm [9]) yields values of 1.5×10^{-7} Ωcm^2 and 4.6×10^{-7} Ωcm^2 for the 4 and 7 nm ALD TiN samples respectively. This means that the specific contact resistance ρ_c is less than these values. These are realistic for high-ohmic metal-metal contacts [11].

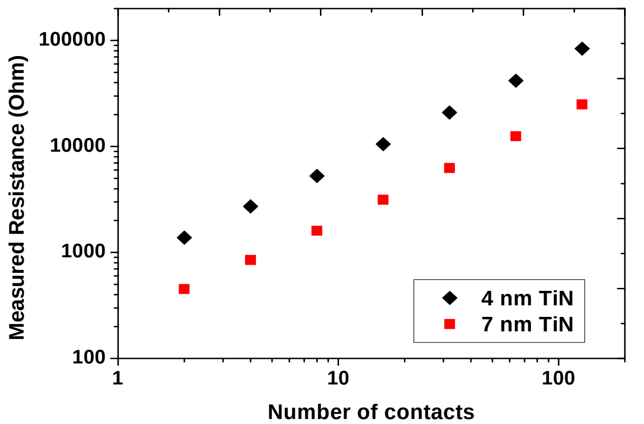


Fig. 6. Measured resistance (R_m) versus the number of contacts for 4 and 7 nm ALD TiN layers.

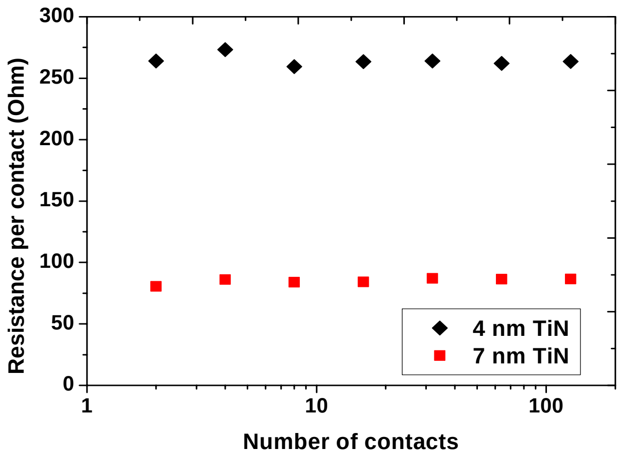


Fig. 7. Resistance per contact (R_c) versus the number of contacts for 4 and 7 nm ALD TiN layers.

IV. Conclusions

Test structures for the electrical characterization of ultra thin conductive films are presented based on buried electrodes on which the ultrathin film is deposited. The contact resistance of the buried electrodes to the ultrathin ALD TiN films is investigated using contact chain structures. For two different sets of contact chain devices containing 4 or 7 nm ALD TiN layers, an average specific contact resistance smaller than 1.5 $\times 10^{-7}$ Ωcm^2 and 4.6 $\times 10^{-7}$ Ωcm^2 was found. These values are realistic for high-ohmic metal-metal contacts.

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