Study of metal line patterning strategy for 300 mm superconducting BEOL

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Introduction:
The development of new Quantum technologies based on superconducting Qubits [1],[2] or spin Qubits[3], [4] becomes a major subject of interest for numerous applications in communication and data treatment. In this context, several approaches enable the fabrication of those devices [5],[6]. In this work a derivative method from VLSI device is chosen with the 28 nm FDSOI technology as a baseline. For this approach operating at low temperature, a superconducting rooting development becomes crucial especially for short distance connections with specific architectures (Fig 1).
Although superconducting material properties are the key targets, these layers also have to be easily integrated in an industrial process flow. Indeed, the selected materials, commonly used in microelectronics, must keep their superconducting properties for narrow lines down to a CD of 100 nm after etching, stripping, cleaning and CMP steps.

1 Superconducting characterisation on blanket wafers
Metallic layers material have been selected based on their critical temperature T_c (higher than 1 K) and their integration capabilities, which led us to consider TaN and TiN. The first step was to characterize their T_c on blanket wafers. All samples resistance versus temperature were measured down to 350 mK. In a previous work, the superconducting properties of a 40 nm thick PVD TaN film were improved by adjusting the N_2 flow during deposition to obtain specific phases [7]. This process development lead to an increase of the T_c up to 2,1 K compared to the standard process with a T_c of 1K (Fig 2). Some recent improvements resulted in a higher T_c of 2,6 K for the same thickness.
For the TiN, the resistance versus temperature is plotted for 3 layers from 10 nm to 40 nm thick and a critical temperature up to 3,6 K is achieved for the 40 nm layer (Fig 3). This is in good agreement with the state of the art [8]. The superconducting properties measured for both materials (TiN and TaN) are compatible with BEOL requirement for quantum application, we will then observe the influence of the patterning on the T_c.

2 Line patterns etching and characterisation
After TiN and TaN layer deposition, the lithography was performed on a 193nm stepper to reach 100 nm line critical dimension. Etching trials were carried out on a 300 mm industrial ICP chamber using Cl_2 chemistry with or without HBr or CH_4 addition. A parametric study of Cl_2 based chemistries was performed to evaluate such criteria as CD profile control, and selectivity between TaN and TiN. Optical Emission Spectroscopy (OES) and Xray Photo-electon Spectroscopy (XPS) were conducted in order to understand the etching mechanisms.
Regarding the TiN, straight profiles (around 85° of steepness) and good CD control (CD bias = 6 nm) are achieved with Cl_2/HBr chemistries but micro masking is observed (Fig 4). The micromasking phenomenon will be further discussed in terms of etching mechanisms. The use of CH_4 instead of HBr overcomes this issue while keeping a good profile (around 81° of steepness) with an etch rate of 70 nm/min (Fig 5). Regarding TaN, lower etch rates are observed in comparison with TiN which might be attributed to a higher Ta-N binding energy and lower by-product volatility (as example 60 nm/min versus 125 nm/min with Cl_2/Ar). A selectivity TiN:TaN of about 4.6 is achieved by adding CH_4 in the Cl_2 based chemistry with an etch rate of 70 nm/min for TiN and 18 nm/min for TaN. Interestingly, the steepness can be controlled from 74° with Cl_2/HBr (Fig 6) to 60° with pure BCl_3 by tuning the etching chemistry.
The T_c of TiN lines etched with Cl_2/CH_4 and TaN lines etched with Cl_2/Ar were measured. The results show only a minor decrease of T_c (-0.2 K) and a small ΔT increase of the TaN lines compared to the blanket results (Fig 7). However, the TiN lines exhibit multiple transitions (Fig 8), which might be explained by an inhomogeneity of the line. We will further discuss those unexpected T_c transitions.

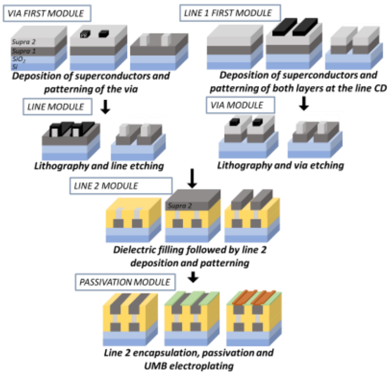

Figure 1 Patterning approach : Process Flow

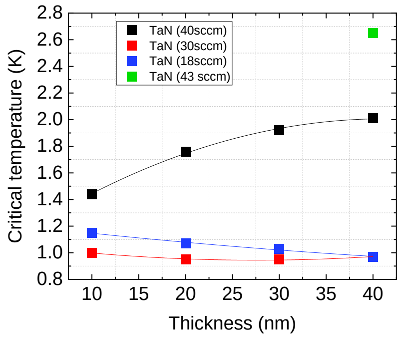

Figure 2 Critical temperature variation of TaN thin film versus thickness and Nitrogen flow, the lines are here to guide the eye

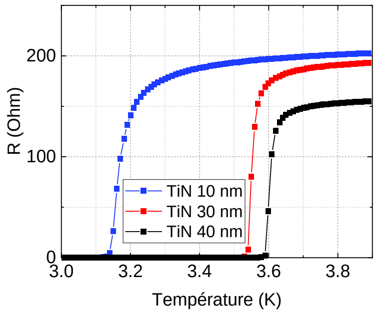

Figure 3 Resistance as a function of the temperature for TiN samples with thicknesses from 10 to 40 nm

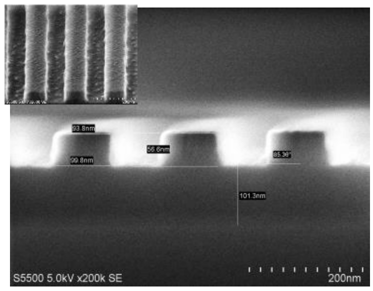

Figure 4 Cross section of 100 nm TiN lines etched with Cl_2/HBr

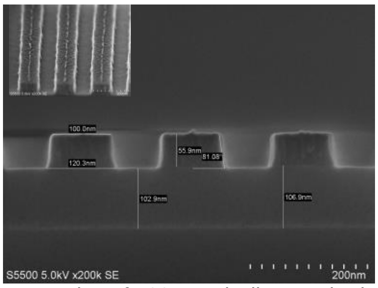

Figure 5 Cross section of 100 nm TiN lines etched with Cl_2/CH_4

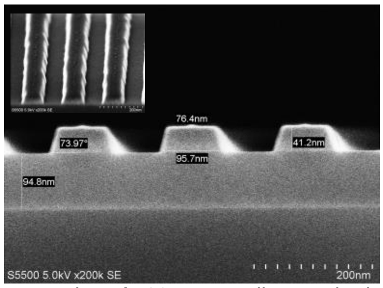

Figure 6 Cross section of 100 nm TaN lines etched with Cl2/HBr

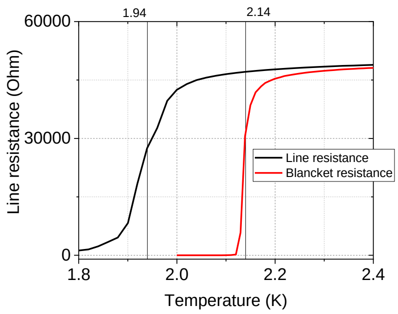

Figure 7 The resistance as a function of temperature for a 100 nm CD TaN line with a length of 60 µm and a blanket TaN layer with a thickness of 40 nm

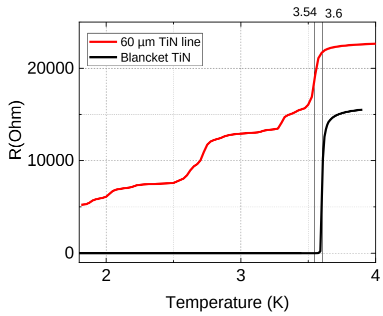

Figure 8 Resistance versus temperature of a CD 100 nm TiN line of 60 µm with a thickness of 40 nm and a blanket TiN layer

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