A DUAL-WORK FUNCTION METAL GATE PROCESS USING DIFFUSION OF NITROGEN FROM A SOLID SOURCE FOR ADVANCED CMOS TECHNOLOGIES

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Continued downscaling of bulk CMOS device dimensions will require the introduction of metal gate electrodes in commercial processes within 6-8 years. This presents many materials and integration challenges, one of the most difficult being the requirement for two electrode materials with the appropriate work functions, one for nMOS and one for pMOS. Ideally, the electrode work-function at the dielectric interface would be adjusted *after* metal deposition, similar to a poly-Si gate process where the work functions are set by implantation of dopants. Direct implantation of metals, such as Mo and Ti, with nitrogen have yielded substantial changes in electrode work function [1-3] but the large implant doses required have been shown to cause catastrophic damage to the gate dielectric [3].

In this study the nitrogen was diffused to the dielectric interface from a layer of over-stoichiometric TiN_{1+x}. This approach allows high concentrations of mobile nitrogen to be located close to the dielectric/metal interface prior to the diffusion anneal and avoids the implant damage to the gate dielectric (see Fig. 1.). The effects of nitrogen incorporation were studied for Mo on SiO_2 and on Al_2O_3 and for Ta on Al_2O_3. RBS measurements have shown that up to 35 at.% nitrogen can be diffused from a $Ti_{0.9}N_{1.1}$ layer into a 10nm Ta layer (Fig. 2) and that this nitrogen concentration is strongly dependent upon anneal temperature.

Theoretical fits to capacitance-voltage measurements have been used to extract the flat-band voltages in MOS capacitors (Fig. 3) and these have shown the work function of Mo to be extremely sensitive to the presence of the TiN_{1+x} layer following anneal at 800°C for 30" (Table 1). The shifts are even larger than those reported from nitrogen implantation studies [1-3] and the shifts are also shown to be dependent upon anneal temperature. In contrast to Mo, the work function of a 10nm Ta layer is shown to be fairly stable to the presence of the $Ti_{0.9}N_{1.1}$ layer following anneal at 800°C for 30". These results of suggest great potential for molybdenum as a candidate for a single-metal dual-work function approach to integrating metal gates into future CMOS technologies.

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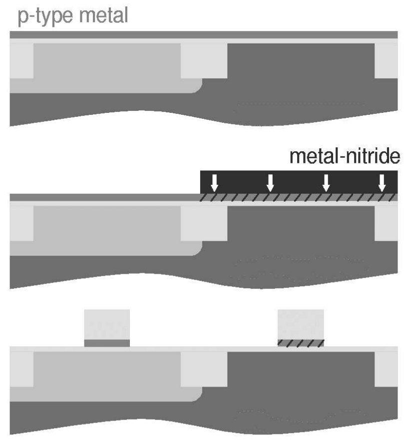

Figure 1. Dual-work function metal gate integration scheme using nitrogen diffusion

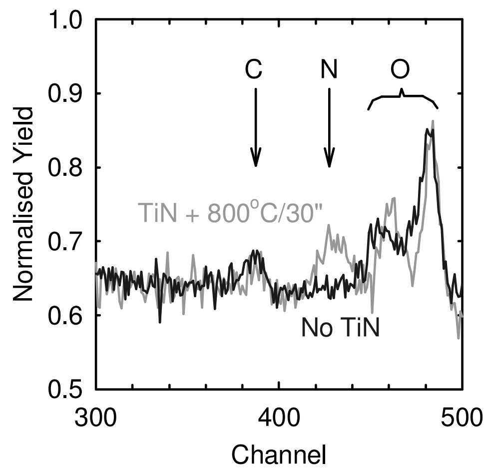

Figure 2. RBS measurements of 10nm Ta layers on SiO_2 following annealing in Ar.

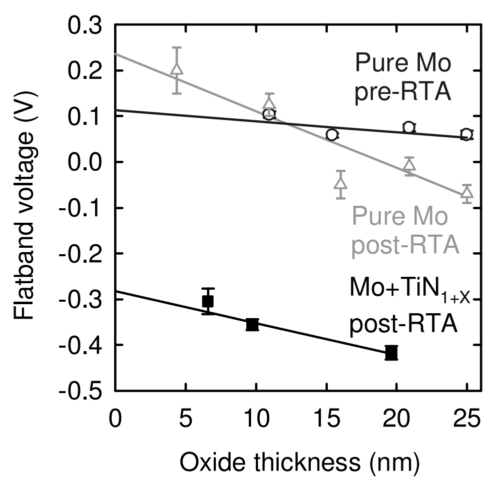

Figure 3. Flat-band voltage of the Mo/SiO_2 samples as a function of SiO_2 thickness

Gate metal/ dielectric stack		ϕ_m (eV)
Mo/SiO_2	Pure Mo (pre-RTA)	5.11±0.04 (4.987±0.013)
	$Mo+TiN_{1+x}$	4.59±0.02
Mo/Al_2O_3	Pure Mo (pre-RTA)	5.75±0.08 (5.53±0.01)
	$Mo+TiN_{1+x}$	4.70±0.09
Ta/Al_2O_3	Pure Ta (pre-RTA)	4.67±0.02 (4.745±0.003)
	$Ta+TiN_{1+x}$	4.59±0.05

Table 1. Electrode work functions obtained from MOS capacitor measurements before (in brackets) and after anneal at 800°C for 30" in Ar.