

EVALUATION OF CMOS GATE METAL MATERIALS USING *IN SITU* X-RAY CHARACTERIZATION

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We present an evaluation of the thermal stability for various elemental metals and binary/ternary conducting alloys on SiO₂ gate dielectrics using *in situ* x-ray diffraction, optical scattering and resistance analysis. The continued scaling of poly-silicon gated CMOS devices may face limitations such as polydepletion, incompatibility with some high-k dielectrics, high series resistance, and boron penetration. In this study, twenty-two different elemental metals and metallic alloys with work functions ranging from 4.0 to 5.2 eV covering nFET, mid gap and pFET gate electrodes were examined. Figure 1 highlights the materials analyzed and indicates the thermal stability range along with the type of work function for each material.

The characterization of the prospective gate metal materials was completed during rapid thermal annealing in a forming gas ambient at a temperature ramp rate of 3 °C/s up to 1000 °C. *In situ* x-ray diffraction, resistance and optical scattering analysis were acquired simultaneously. In addition, *ex situ* x-ray reflectivity analysis was also completed. It was found that many of the materials, especially those with nFET work functions found in columns 4 and 5 of the periodic table, undergo reactions with the SiO₂ while others were unstable because of melting (Al) or agglomeration (Co, Ni, Pd and CoSi₂). Figure 2 shows an x-ray contour plot of Ti on SiO₂ where x-ray angle (two theta) and x-ray intensity (gray scale) are plotted versus temperature. The Ti(002) peak deviates from a linear increase, due to thermal expansion, at about 400 °C. This indicates an interaction with the FG ambient (Fig. 2a) and the underlying SiO₂ (Fig. 2b).

The materials stable up to 1000 °C include W, Re, Rh, Ir, Pt, TaN and TaSiN making them possible gate metal choices for integration involving high temperature processing. The x-ray contour plot in Fig. 3a shows that Pt (Pt(111) peak) is stable on SiO₂ up to 1000 °C.

Two binary compounds, RuO₂ and W₂N, underwent dissociation in the hydrogen containing forming gas annealing ambient. Figure 3b shows the dissociation of RuO₂, occurring at about 150 °C.

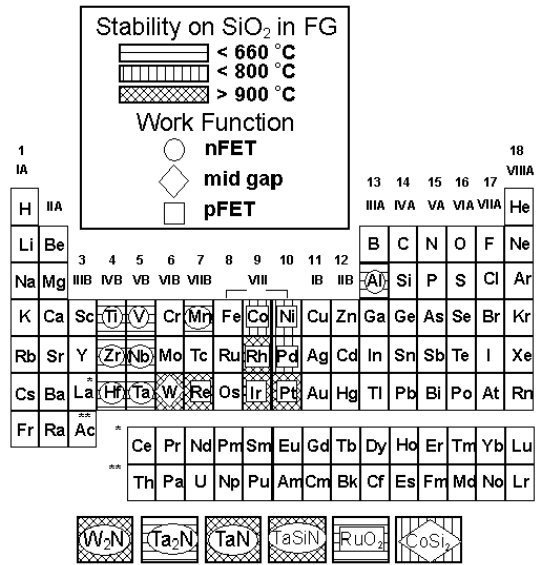


Fig. 1. Thermal stability of various gate metal materials in contact with SiO₂

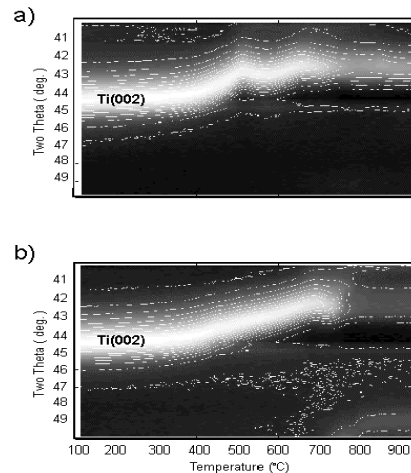


Fig. 2. Thermal stability of 30 nm of Ti in contact with SiO₂. Annealed in (a) FG and (b) He. X-ray intensity is shown as a gray scale with white indicating the highest intensity ($\lambda = 0.18$ nm).

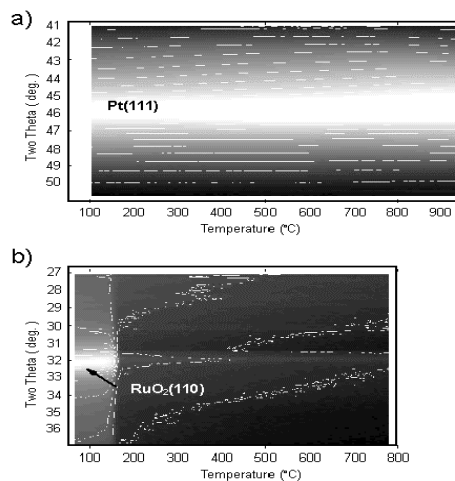


Fig. 3. Thermal stability of (a) Pt and (b) RuO₂ materials in contact with SiO₂. Annealed at 3 °C/s in FG. X-ray intensity is shown as a gray scale with white indicating the highest intensity ($\lambda = 0.18$ nm).