$PtCoO_2$ delafossite oxide thin films for advanced interconnects

Jean-Philippe Soulié[a,*], Ho-Yun Lee[a], Seongho Park[a], Zsolt Tőkei[a], Christoph Adelmann[a]

[a] *Imec, IMEC, Kapeldreef 75, 3001 Leuven, Belgium*

The ongoing miniaturization of device densities in both logic and memory circuits necessitates a commensurate reduction in the dimensions of interconnect lines. In state-of-the-art microelectronic chips, the characteristic dimensions of interconnects are now approaching 10 nm, with future projections indicating even smaller scales. While elemental metals were initially explored as potential replacements for Cu in interconnect line metallization to enhance resistance and reliability, recent research has shifted toward binary [1] [2] [3] and ternary intermetallic compounds due to their advantageous material properties and superior performance potential.

Among the ternary candidates under investigation, delafossite oxides have emerged as promising materials for advanced interconnects. Notably, the delafossite oxide $PtCoO_2$ exhibits a bulk resistivity of just 2.1 $\mu\Omega$cm, lower than aluminium [4]. The structure of $PtCoO_2$ comprises alternating layers of Pt and Co cations, separated by O atoms. The Pt layers form a triangular lattice, while the Co layers reside in octahedral coordination with oxygen. This highly anisotropic material demonstrates excellent in-plane conductivity, albeit with reduced out-of-plane conductivity.

Our work has focused on the epitaxial growth of $PtCoO_2$ thin films on c-plane sapphire substrates to mitigate grain boundary scattering. As deposited films are amorphous and oxygen deficient, requiring a post-deposition annealing process at 700-800^{o}C in an oxygen atmosphere. 2D reciprocal space mapping, conducted using a Rigaku SmartLab diffractometer, confirms the epitaxial growth of delafossite $PtCoO_2$ following annealing, with the characteristic (006) diffraction peak observed (Fig. 1a). The resultant films exhibit a (001) oriented delafossite phase. The epitaxial relationship between $PtCoO_2$ and the c-sapphire substrate is further validated by the six-fold symmetry observed in the pole figure for the (214) reflection (Fig. 1b). Platinum, a secondary phase, is also detected post annealing, consistent with a previous study [5]. Rocking curve analysis of the sample yields a full width at half maximum of 0.96^{o}, indicative of good crystalline quality (Fig. 1c).
Transmission electron microscopy (TEM) analysis has been employed to investigate the microstructure of the delafossite oxide. As shown in Fig. 2, the layered structure of $PtCoO_2$ is clearly observed, epitaxially grown on the sapphire substrate. Fast Fourier transform (FFT) analysis reveals the crystallographic orientation relationship: $(0001)_{PtCoO2}$ // $(0001)_{Al2O3}$. However, defects and instabilities are evident in the $PtCoO_2$ layer post-annealing (Fig. 3). Observed issues include void formation (Fig. 3a), internal delamination across various film thicknesses (Fig. 3c), and Pt loss/move during annealing (Fig. 3b), even in an oxygen-rich atmosphere. These phenomena suggest a competition between crystallization and decomposition processes. Additionally, the rough interface between Al_2O_3 and $PtCoO_2$ highlights further challenges. These defects require careful analysis and optimization in future process iterations, as they indicate a narrow process window for achieving phase stability and uniform nucleation.
Despite these challenges, $PtCoO_2$ films exhibit low resistivity values ranging from 11 and 17 $\mu\Omega$cm at thickness of 5 to 27 nm after annealing at 800^{o}C in oxygen atmosphere. These values position delafossite $PtCoO_2$ as a promising candidate for advanced interconnects metallization.

References

1. D. Gall, 2020 IEEE International Symposium on VLSI Technology, Systems and Applications, 112 (2020).
2. L. Chen *et al.*, J. Appl. Phys. **129**, 035301 (2021).
3. J-Ph. Soulié *et al.*, J. Appl. Phys. **136**, 171101 (2024).
4. A.P. Mackenzie, Rep. Prog. Phys. **80,** 032501 (2017).
5. D.J. Hagen *et al.*, Adv. Mater. Interfaces **9**, 2200013 (2022).

[*] *corresponding author e-mail: jean-philippe.soulie@imec.be*

Figure 1: XRD measurements of delafossite $PtCoO_2$ thin films

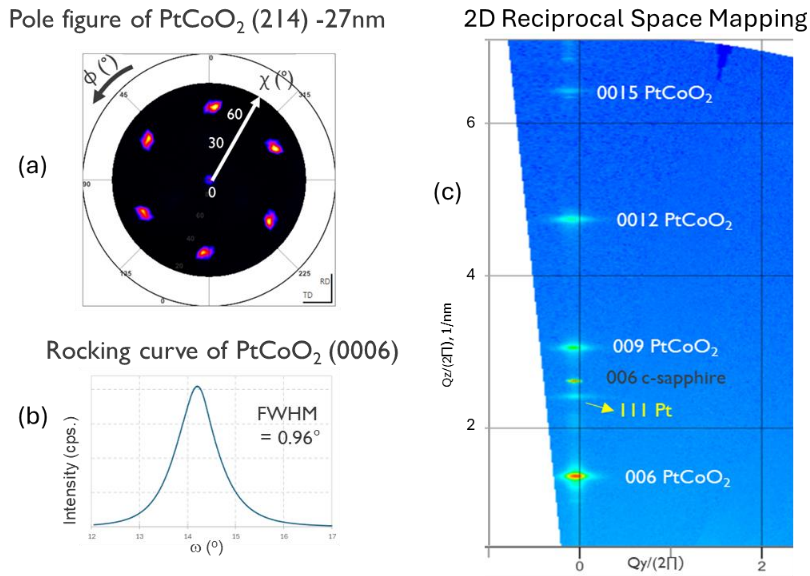

Figure 2: Cross-TEM image and Fast Fourier Transform of $PtCoO_2$ thin film

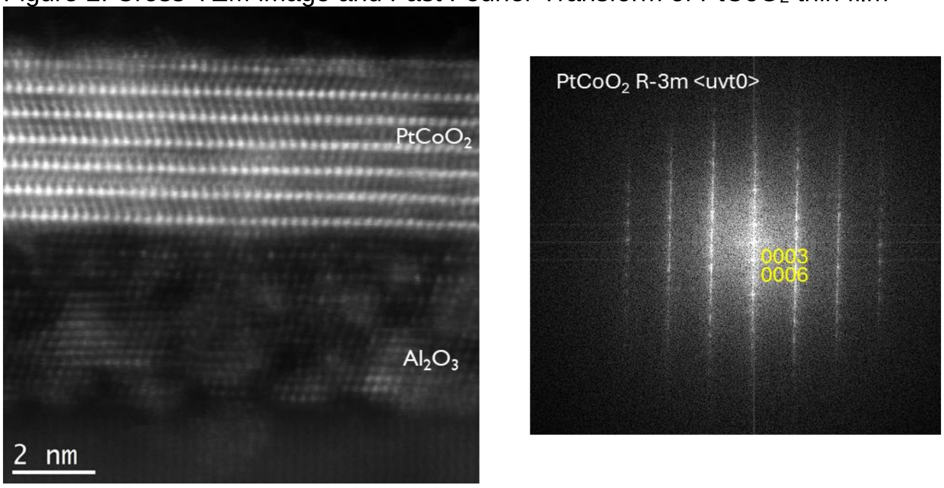

Figure 3: Defectivities seen by Cross-TEM for the $PtCoO_2$ thin films