Quasi-2D Materials for Ultra-Low Resistance Electrical Interconnects

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Abstract:

The dramatic increase in the resistivity of interconnect lines with decreasing dimensions presents a significant bottleneck for further downscaling of integrated circuits [1]. This is because current interconnects use 3-dimensional metals that experience increased interface electron scattering as the interconnect dimensions approach their electron mean free path. A possible solution is to use metals with much lower electron mean free paths such as: W, Mo, and Ru. Metallic delafossite oxides are an alternative solution because of their inherent advantages over traditional metals such as: ultra-low room temperature resistivity, potential mitigation of interface/surface scattering due to their 2D Fermi surface, potentially decreased likelihood of electromigration, and potentially better compatibility with low-κ oxide dielectrics. Metallic delafossite can prove to be a disruptive new material for ultra-scaled electrical interconnects.

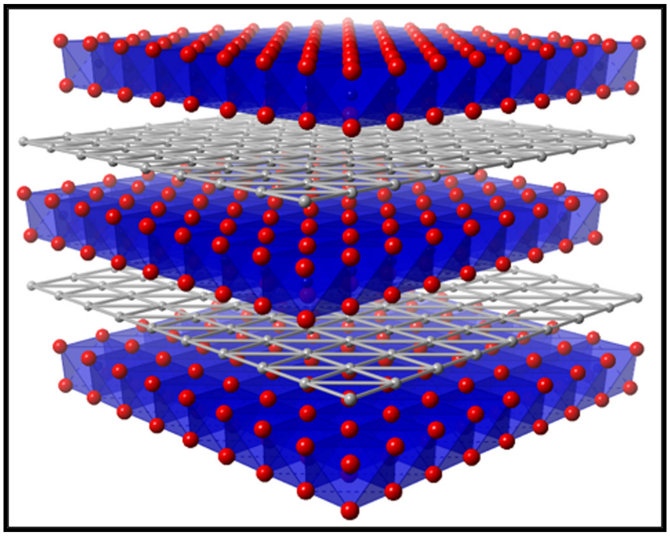

Figure 1: Crystal structure of delafossite PtCoO2 illustrating the sheets of Pt responsible for the anisotropic conductivity.

Introduction:

Delafossites are layered oxides with the formula ABO_2 where A is a metal cation that forms 2D sheets separated by the BO_2 transition-metal oxide octahedra, Figure 1. In this study we focus on metallic delafossites $PtCoO_2$ and $PdCoO_2$ because of their ultra-low room temperature resistivity of 2.1 $\mu\Omega$.cm and 2.6 $\mu\Omega$.cm, respectively, which is comparable to the current semiconductor industry standard interconnect metal, Cu, Figure 2 [2]. The metallic delafossite structure has an anisotropic nature with resistivity along the c-axis a factor of 1000 higher than resistivity within the Pt/Pd sheet. Due to the layered crystal structure, the Fermi surface of the metallic delafossites is cylindrical as for a 2D metal. This quasi-2D crystal structure can potentially mitigate interface and surface scattering since the electron Fermi velocity does not have components perpendicular to the Pd/Pt sheets. This can potentially overcome the resistivity penalty encountered by conventional 3D metals in ultrathin films (< 20 nm). Additionally, the unique Fermi surface topology allows for an electron-phonon coupling constant that is a factor of 3 lower than copper [3].

Our focus has been to demonstrate metallic delafossites as a disruptive new material for ultra-scaled electrical interconnects, for which we have two goals. The first goal is to realize their unique electrical properties and the second goal is to demonstrate the growth of highly quality delafossite thin films via atomic layer deposition (ALD) a back-end-of-the-line (BEOL) compatible synthesis technique.

Summary of Research:

To realize the unique electrical properties of delafossite thin films we have been investigating the structural and electrical properties of $PdCoO_2$ thin films grown via molecular beam epitaxy (MBE). MBE has been shown to achieve highly crystalline films which is critical for electrical property characterization due to the structure-property relation [4,5]. We used high-resolution X-Ray diffraction (HRXRD) to confirm that the films are phase-pure. We measured the resistivity of the films using a van der Pauw geometry and modelled the resistivity scaling with film thickness using Fuchs-Sondheimer (FS) and Mayadas-Shatzkes (MS) model. The upshot being that a 50 nm thick $PdCoO_2$ film has a resistivity of 5 $\mu\Omega$.cm. It should be noted that while our XRD phi scans did reveal in-plane twinning our resistivity fitting did not find twin boundaries to be a significant contributor to resistivity.

We have also combined thermodynamic modelling with *ex-situ* annealing to characterize the amorphous to crystalline transition in molecular beam epitaxy (MBE) grown $PdCoO_2$ thin films. This characterization was very insightful in finding the relevant temperature range and secondar phases. This characterization allows us to transition from MBE to BEOL-compatible ALD which typically deposits amorphous films. This complements our ALD growth $PtCoO_2$ thin films for which we are currently calibrating the Co_xO_y and PtO binary cycles to later combine into the $PtCoO_2$ supercycle.

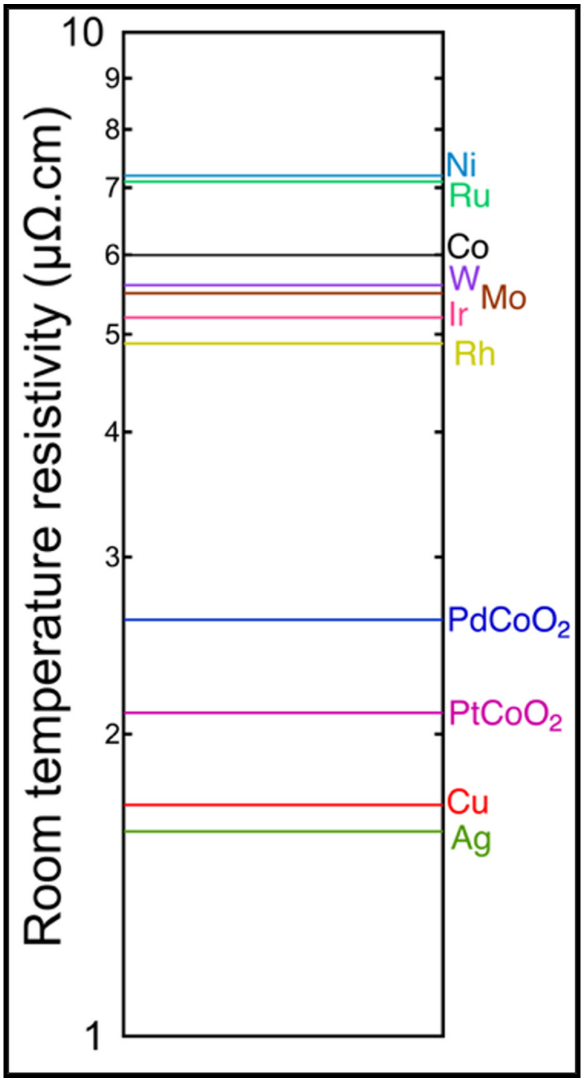

Figure 2: Comparison of room temperature resistivity of $PdCoO_2$ and $PtCoO_2$ to conventional interconnect metals.

Conclusions and Future Steps:

We have two main future goals: (1) The first goal is to characterize electrical properties in decreasing dimensions, similar to interconnect dimensions, for which we are planning to fabricate nanowires of MBE-grown $PdCoO_2$ thin films, via photolithography and e-beam lithography, and (2) the second goal is to demonstrate the growth of highly crystalline $PtCoO_2$ films via ALD and post-deposition annealing.

References:

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