Tailoring growth interfaces of virtual substrates for power electronics

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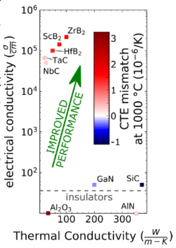
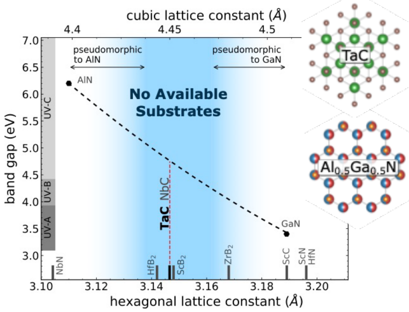
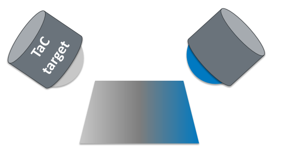
Transition metal carbides as $Al_xGa_{1-x}N$ substrates

$Al_xGa_{1-x}N$ is a prime candidate for power electronics applications given its bipolar dopability, high mobility, structural stability, and other intrinsic properties but much of the composition range is pseudomorphically inaccessible. While solutions have been proposed, ultimately a lattice-matched substrate is needed. We propose **transition metal carbides and nitrides**, i.e. TaC, due to lattice compatibility, suitability for vertical devices, and limited CTE mismatch.

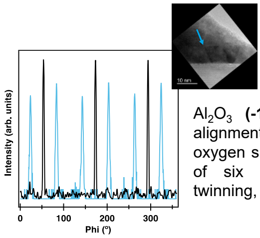




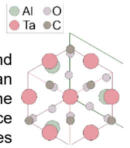
TaC thin film growth by RF sputtering



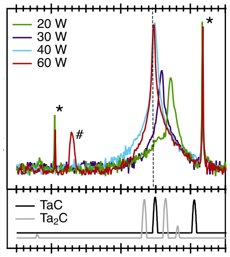
TaC thin films are deposited via RF sputtering at 5 mTorr and highest achievable growth temperatures, here ~730 °C. Thin films are deposited on sapphire substrates that have been cleaned and annealed at 1100 °C.



Rotational x-ray diffraction scans of the TaC (002) and Al_2O_3 (-102) planes show an alignment of the TaC with the oxygen sublattice. The presence of six TaC peaks indicates twinning, shown above.

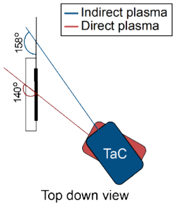


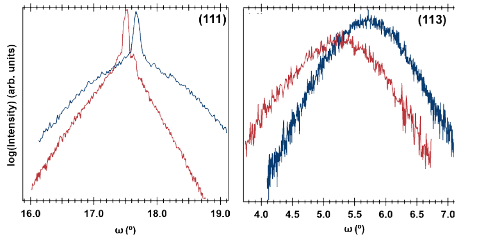
Growth optimization



Sputter gun power affects both phase purity – the film at 20 W contains TaC and Ta_2C – and lattice constant. This could also prove a useful parameter for tuning lattice constant and accessing other $Al_xGa_{1-x}N$ compositions

* = substrate
# = stage

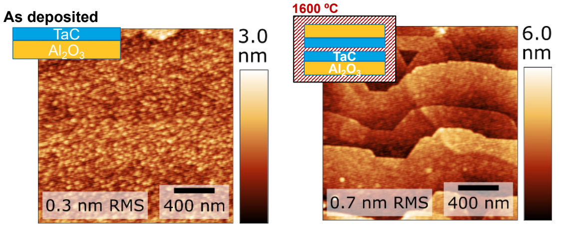




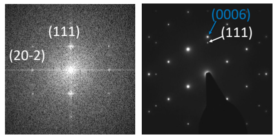
The incident angle of the sputter plasma on the substrate surface affects film quality. The rocking curves above demonstrate changes to in-plane (111) and out-of-plane (113) strain, lattice parameter, and domain size. Indirectly sputtered films have smaller FWHMs.

Improving surfaces via high temperature annealing

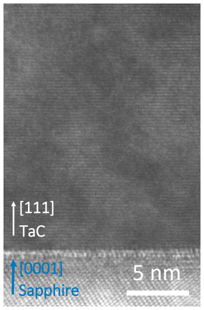
Film structure and morphology is significantly improved after annealing at high temperatures in a face-to-face configuration. We anneal films at and above 1500 °C, approximately 40% of the 3880 °C melting point.

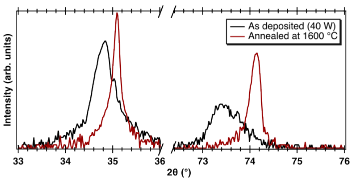


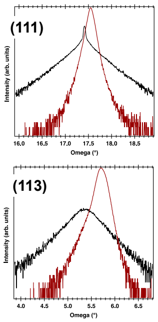
Atomic force microscopy of the film surface as deposited (left; typical columnar grains) and after annealing (right; step terracing).



High resolution transmission electron microscopy (right), Fourier transform (center) and electron diffraction (left) of TaC thin film annealed at 1500 °C.







Overall structural improvements are demonstrated by reduced full width at half max (FWHM) XRD patterns and in-plane and out-of-plane (top and bottom right, -respectively) rocking curves. No secondary phases are detected. Films also densify and shift to slightly larger lattice constants.

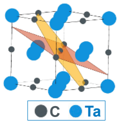
Calculated structural distortions

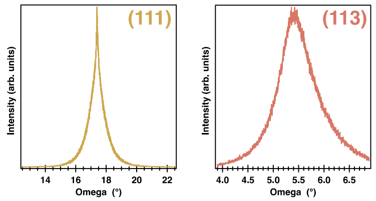
There is a significant lattice mismatch between the sapphire substrate and the grown TaC thin film. Thickness, incident plasma angle, and annealed state have an effect on film structure. Below are the cubic distortions away from α = 90° for different film conditions calculated from the angle between (113) and (331) planes

Sample	α (°)	a (Å)
50 nm, direct, as deposited	90	4.45
50 nm, indirect, as deposited	89.6	4.37
150 nm, indirect, as deposited	89.5	4.41
150 nm, indirect, annealed	89.7	4.42

Phase characterization

The (111) face of cubic TaC is very close to the lattice spacing of the (002) face of hexagonal Ta_2C. To differentiate between the two phases phases we determine the presence of the (113) plane with x-ray rocking curves, as this angular offset is unique to TaC.





Future directions

- Develop TaC growth on SiC, a conductive substrate
- Optimize annealing conditions
- Investigate lattice tunability
- Further develop growth of $Al_xGa_{1-x}N$ on TaC virtual substrates

See poster by Dr. Brooks Tellekamp, TuM-37

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