

# Journal of **Vacuum Science & Technology**



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# Journal of Vacuum Science & Technology

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# Journal of Vacuum Science & Technology

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by a chemical vapor deposition process involving the reaction of trimethyl aluminum gas with ammonia in the presence of hydrogen at temperatures of approximately 1200 °C. Using a modified epireactor as the growth furnace with a gas injection system that directs gas flow onto the substrate, growth rates of 500 Å/min are achieved producing films over 10 μm in thickness which exhibit excellent mechanical and chemical stability.

The *R*-plane, (01 $\bar{1}2$ ), of sapphire consists of alternate layers of Al and O with a repetitive sequence of O-Al-O-Al-O. In the two different layers of atoms, the Al atoms occur in a close-packed configuration while the O atoms are aligned into columns along the [0 $\bar{1}11$ ] direction. The hexagonal wurtzite structure of AlN has the (11 $\bar{2}0$ ) plane consisting of coplanar atoms of Al and N in a close-packed configuration but segregated into columns aligning with the [0001] direction. A good fit of these two planes is obtained when the columns of atoms are aligned with the sapphire [0 $\bar{1}11$ ] and AlN [0001] directions colinear (i.e., with the AlN *c* axis pointing in the same direction as the projection of sapphire *c* axis upon the *R* plane), giving lattice mismatches of 2.7% along and 11.9% across the [0 $\bar{1}11$ ] direction. A reversal of the AlN [0001] axis however, places the AlN atoms in the interstitial sites of sapphire indicating poor lattice matching.

The as-grown surface morphology of the AlN films, as examined under a scanning electron microscope, can be divided into two categories. Category I features very

distinctive scale-like facets that are all aligned in one direction while category II includes the scale-like facets aligned but pointing in opposing directions along with some spurious nucleations. X-ray analysis of the sapphire substrate shows the facets to be that of the AlN [0001] axis aligning with the [0 $\bar{1}11$ ] direction of the *R* plane.

Surface-acoustic-wave measurements of the AlN films are made by reflective impedance measurements from Al interdigital transducers fabricated upon polished surfaces. There is a definite correlation between the quality of the results and the category of the surface morphology. Results obtained from films of category I were consistently better than those obtained from films of category II leading to the confirmation of the theory that there is a preferred direction of growth of AlN [0001] axis upon the *R* plane for minimum stress with maximum lattice matching.

Surface-acoustic-wave coupling constant  $K^2$  and propagation velocity  $V_s$  are measured out to an AlN thickness to transducer wavelength ratio  $t/\lambda$  of 0.75 with typical  $K^2$  values of 0.8% and  $V_s$  of 6.1 km/s.

Preliminary results obtained from a study of the dependence of the  $K^2$  versus  $t/\lambda$  curve upon transducer wavelength indicate that the AlN-sapphire interfacial strain extends about 1 μm into the AlN film.

\*J. K. Liu, K. M. Lakin, and K. L. Wang, *J. Appl. Phys.* **46**, 3703 (1975).

## Abstract: Measurement of interfacial bond strength by laser spallation

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What is normally referred to as "adhesion" of a thin film to a substrate is, in reality, the sum of five forces. There are three possible attachment forces: electrostatic, van der Waal's, and chemical bonding. The detachment forces are stress in the film and at the film-substrate interface and any externally applied forces (e.g., scratching, abrasion, peeling, etc.). Virtually all of the so-called "adhesion tests" that have been described should really be called "service use tests," in that they test for failure in a particular fracture mode. As a result, quantitative information regarding interfacial bond strength cannot be derived. Further, common to all these tests is the requirement that the film surface be disturbed (e.g., by attaching something to the surface, scratching it, etc.). The very act of disturb-

ing the surface could propagate mechanical damage to the interface and further cloud the results when quantitative information about the bond strength is desired.

The bond strength of a thin film to a substrate can be measured quantitatively, with no contact to or disturbance of the film surface prior to measurement by a laser spallation technique. The technique involves impinging a pulsed, high-energy, Nd-glass laser beam (1.06 μm) onto the back surface of a substrate (made opaque in the case of transparent substrates). The explosive evaporation of absorbing material on the back side of the substrate generates a compressive shock wave in the substrate directed toward the film-substrate sur-

face. The magnitude of the shock wave can be varied to establish a threshold for spallation or detachment of the film from the substrate. With appropriate corrections for shock wave damping in the substrate and stress in the film, the technique can yield quantitative information about the bond strength of the film to the substrate.

Ideally, the film should be patterned into dots of a size such that the entire dot can be detached with one laser shot. This avoids the problem of measuring the sum

of the film-substrate bond strength and the tensile strength of the film. Further, it is possible in some cases to examine the back side of a spalled dot and the front side of the substrate from which the dot was spalled by various surface analytic techniques to gain insight into the mechanisms by which interfaces are formed.

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