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Plastic strain relaxation in heteroepitaxy: A critical comparison of mechanisms and processes in III-Nitride epilayers

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The concept of critical thickness has been dominant in defining the plastic behaviour of epitaxial layers. In this respect, the description of the phenomenon is based on the introduction of misfit dislocations at the heteroepitaxial interface in order to relieve the elastic strain due to the substrate. On the other hand, a crucial issue concerns the availability of glide mechanisms that will permit this to actually take place. If such an availability is limited, the system will seek other routes as an alternative to cracking.

III-nitrides constitute a model system to demonstrate this, since, due to the hexagonal lattice, there is no resolved shear stress on the primary slip systems in the cases of polar and nonpolar growth. Only when the epitaxial orientation is semipolar, such a resolved shear stress can exist. Also, in addition to being grown in alternative orientations, III-nitrides are usually grown as alloys of the general form $In_xAl_yGa_{1-x}N$, so that a compositional interplay is also possible under the influence of elastic strain.

We will compare the response of In(Ga)N/GaN and Al(Ga)N/GaN heterostructures to the misfit-induced plane stress. InGaN and AlGaN alloys differ significantly on the bond strength and adatom mobilities. Based on detailed structural observations by transmission electron microscopy (TEM) and high resolution TEM (HRTEM) methods, we will discuss the alternative routes to misfit dislocation introduction such as the inclination of the threading dislocations, stacking fault folding, opening of V-pits, chemical grading or zoning of the films, and interfacial grading versus interfacial roughening. Such mechanisms pertain to either films or very thin layers such as quantum wells, and it is important to consider the cumulative elastic strain energy stored in the system for the onset of plastic relaxation. Overall, a description of the strain relaxation of such heterostructures requires a separate definition of a critical thickness for each mechanism, as they may operate in succession in response to the residual elastic strain.