Geometrical selection during MBE growth of nanowires on polycrystalline substrates

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If semiconductor nanowires (NWs) are to be applied in electrically driven devices they should be well-oriented relative to the substrate normal. This requirement is easily fulfilled if NWs are formed by self-assembly on amorphous substrate. Then there are no epitaxial constraints and NWs grow perpendicular to the substrate surface. If, however, NWs are strongly linked to a polycrystalline substrate, their random orientation is expected due to an arbitrary arrangement of substrate grains, eventually impeding application of such NW array.

In this work we show that unidirectional supply of material fluxes in molecular beam epitaxy (MBE) favors growth of well-oriented NWs even despite random orientation of grains on which epitaxially linked NWs nucleate. We present a geometrical model describing an impact of MBE system geometry on the orientation of the NWs. Specifically, we calculated effective area of the nanowire's top facet S_{eff} that is in the line of sight of an effusion cell as a function of nanowire tilt relative to substrate normal (α) and substrate rotation angle (ω) (see Fig. a). The S_{eff} value is equivalent to the number of atoms incorporated on the NW top facet which, in the framework of the model, controls axial growth rate of the NW. For example, this is the case of metal-limited MBE growth of A_3B_5 NWs. Fig. b shows normalized value of S_{eff} as a function of α and ω. As seen, the maximum of S_{eff} corresponds to the NW facing directly in the direction of the effusion cell (α = 40º, ω = 0º) as expected. However, during rotation of the substrate the fastest growing nanowires are the ones that are perpendicular to the surface (Fig. c). To verify the model we grew GaN NWs on ZrN polycrystalline buffers. Without substrate rotation the NWs grew uniformly arranged at α = 40º, ω = 0º (Fig. d), i.e. exactly as predicted by our model. Standard growth with rotation of the substrate led to densely packed NWs with significantly limited tilt dispersion (Fig. e). We attribute this behavior to the shadowing of strongly tilted NWs by preferentially grown perpendicular ones.

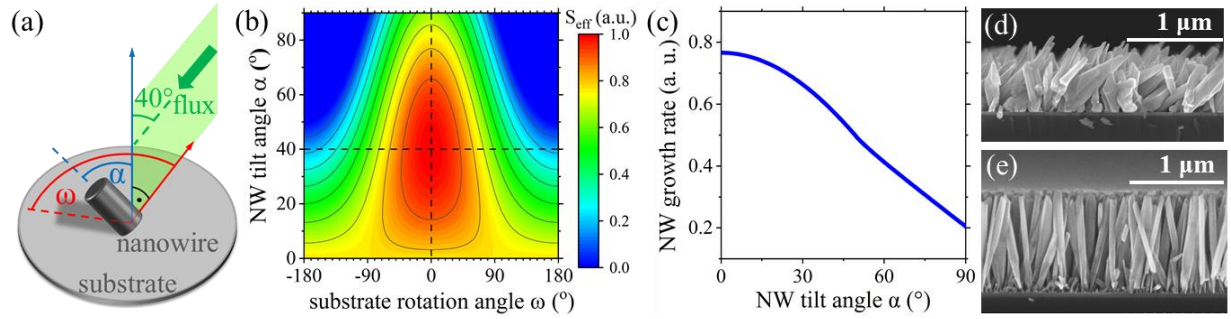

Fig. (a) geometry of the system; (b) effective area S_{eff} of the NW top facet as a function of α and ω angles; (c) average NW growth rate after entire substrate rotation as a function of the NW tilt α. SEM images of GaN NWs grown on ZrN buffer without (d) and with (e) substrate rotation.

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