A Comparison of MOVPE and MBE Growth Technologies for III-V Epitaxial Structures

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Which is better, Molecular Beam Epitaxy (MBE) or Metal-Organic Vapor Phase Epitaxy (MOVPE)? The obvious answer is "it depends." From a purely technical perspective, choosing the best growth technology is based on the precise details of the grown structure and end application. Commercially, the appropriate choice is strongly impacted by the cost profile for each technique and the specific capacity profile inherent to a specific product type. However, the choice of the appropriate technique is often mired by a complicated mix of "half-truths", folklore, and historical notions that are applied by both sides of the debate. A survey of the technical and commercial strengths and limitations of each technology based on first-hand expertise will be provided. Throughout, certain common notions will be challenged.

To assess the merits of each technique, it is necessary to start from the basics of each technology:

MBE

MBE is growth on a heated substrate in ultra-high vacuum (UHV) environment (base pressure ~1E-9 Torr) typically using elemental sources. The UHV environment not only ensures material purity, but it also results in highly directional elemental beams (no carrier gas required) due to the inherently long mean free paths. Layered structures are achieved by shuttering. In addition, valved sources are typically used for group V materials due to their relatively high vapor pressures. In addition to elemental components, it is possible to use compound decomposition sources (e.g., GaTe for Te doping), gas sources (e.g., CBr_4 for C doping), and plasma sources (e.g., N plasma for nitride applications).

MOVPE (aka OMVPE or MOCVD)

MOVPE also grows on a heated substrate but in a much different pressure regime than MBE (typically 15 to 750 Torr). Rather than elemental sources, MOVPE uses more complex compound sources, namely metalorganic sources (e.g. tri-methyl Ga, In, Al, etc.), hydrides (e.g., AsH_3, etc.), and other gas sources (e.g., disilane). In MOVPE, the reactants are flowed across the substrate where they react resulting in epitaxial growth. In contrast to MBE, MOVPE requires the use of a carrier gas (typically H) to transport reagent materials across the substrate surface. Layered structures are achieved by valve actuation for differing injection ports of a gas manifold.

Table 1: MBE vs. MOVPE comparison

Category	Advantages of MOVPE	Advantages of MBE
Technical	High growth rate for bulk layers	Fast switching capability for superior interfaces
	Growth near thermodynamic equilibrium, excellent quality / crystallinity	Able to growth thermodynamically "forbidden" materials
	Ability to explicitly control the background doping	No hydrogen passivation inherent to MOVPE, no "burn-in"
		Uniformity easier to tune (largely set by reactor geometry)
Commercial	Shorter Maintenance periods	Longer individual campaigns, less setup variability than MOVPE
	More flexibility for source and reactor configuration changes	
	Higher safety risk ….increasing scrutiny by legislative bodies worldwide	Lower material cost per wafer
	Economic to idle. Overhead cost scales with run rate.	Overhead does not scale significantly with run rate. Contribution/wafer increases with volume.

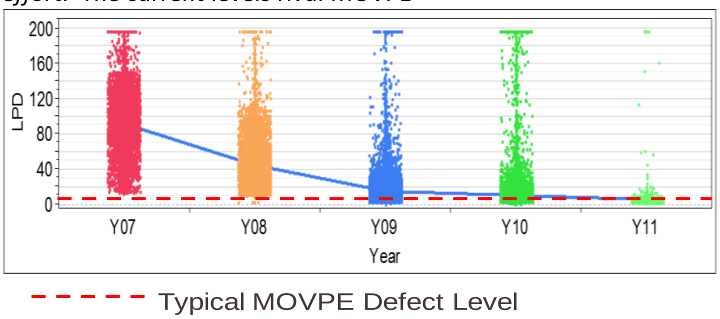
Based on this table, one can start to develop some generalizations that have long been held in the materials community. Two examples:

- "MOVPE is better for thick opto structures (e.g., solar cells)"
- "MBE is better for structures with thin alternating layers (e.g., PHEMTs)"

Although these examples have significantly impacted how the epi industry has "grown" up, both have been challenged and found to not be universally true. For example, Solar Junction has achieved a world-record for CPV solar cell efficiency using MBE [1]. In addition, high quality PHEMT epi can be grown by both MBE and MOVPE. The precise reasons for these deviations will be discussed as a means to highlight how historic notions and "half-truths" can be misleading.

One notable absence from Table 1 is defectivity. It has been a long held belief that MOVPE will always be able to provide lower defect levels. In fact, text books on epitaxial technology state this difference as inherent to the techniques – a scientific fact [2]. The reality of the situation is that MBE can be made as capable of MOVPE with the appropriate equipment design improvements and adoption of some of the engineering advances that have benefitted MOVPE. Figure 1 shows an example of how such innovation can be employed to reduce defectivty for MBE reactors. This case will be discussed further as an example of how historic perception should be challenged with engineering innovation.

Figure 1: Defect Improvement Example for MBE for a typical volume product for one of IQE's MBE sites. *The reduction in LPD year-on-year is the result of concerted equipment engineering effort. The current levels rival MOVPE*



From the commercial side, there is one key consideration regardless of the precise technical merit of a given epi growth technique. As noted in Table 1, the cost profiles for each technique are very different due to the specific utility/overhead requirements for each. For MOVPE, the overhead costs tend to scale with production volume. In contrast, for MBE the overhead is relatively fixed, and does not scale with volume. Therefore, MOVPE wins in a situation of significant overcapacity (significant idle time), and the opposite is true for MBE which excels on a cost basis when fully loaded. The specifics for this will be discussed along with how this can be exploited depending on the specific production scenario.

[1] rdmag.com. 15 August 2012. R & D Magazine. 26 November 2012. < http://www.rdmag.com/award-winners/2012/08/most-efficient-pv-date>.

[2] Stringfellow, Gerald B. Organometallic Vapor-Phase Epitaxy. San Diego, CA: Academic Press, 1999, p. 6