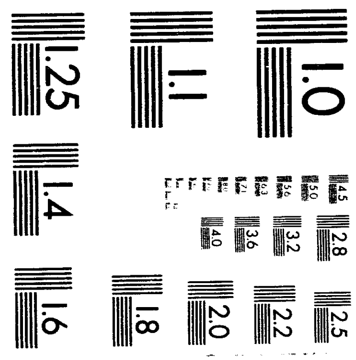
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1 of 1

Advances In MOVPE Compound Semiconductor Epitaxy Manufacturing Technology: From High Throughput Large Area Reactors to Cluster Tools

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The digital electronics and optoelectronic compound semiconductor industry is one of the critical dual-use technology areas of our nation and the world for the 90's and into the next century. Digital electronics find applications in high speed (wireless) communications, microwave devices, and high speed computers. Optoelectronic devices are used in all aspects of communications (lasers and detectors) and displays (LEDs). As production levels of these material systems increases, the need for economical, high yield equipment capable of producing these materials with high levels of uniformity and repeatability rises. Leadership in commercial/military optoelectronic and digital markets requires leadership in equipment and process technology. Production features must emphasize reliability (maximum MTBF), repeatability, improved safety, serviceability (minimum MTTR), economical operation, flexible manufacturing, and compatibility with integrated manufacturing.

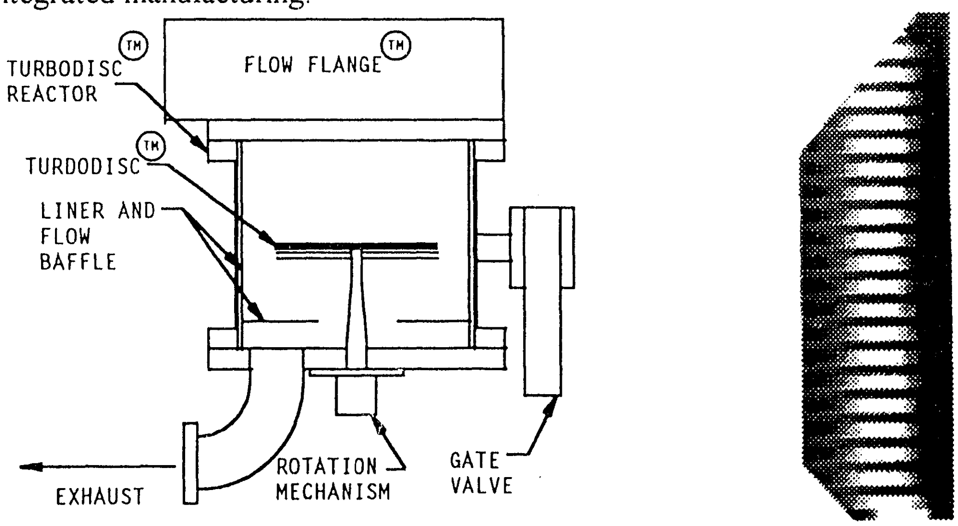


Figure 1a) Rotating Disk Reactor schematic; 1b) TEM cross section (courtesy of SIEMENS) showing repeatability of 20 layers of InGaAs (7nm)/InGaAsP (wavelength=1.25 um, 10nm) structure produced in a RDR

Molecular Beam Epitaxy (MBE) and Metal Organic Vapor Phase Epitaxy (MOVPE) are the two leading production deposition technologies. In recent years, MOVPE has become the more versatile and more economical production technology. We have embarked on a next generation MOVPE systems development path which meets the large scale, high throughput needs of this growing high technology market, both today and tomorrow. The leading design for high-throughput MOVPE reactors is the EMCORE

This work was supported by the United States Department of Energy under Contract DE-AC04-94AL85000.

high-speed rotating disk reactor (RDR) which is shown in figure **1a** and whose benefits have been reported by several authors [1].

Extensive modeling of RDRs has been performed by several organizations including EMCORE and SNL. Such modeling studies confirm that the RDR system can be scaled to large dimensions and can be used to produce highly uniform films over large areas. We will review modeling results and compare them with material results. For example, depositions on 4-4" (100mm) wafers on a 12" (300mm) diameter susceptor (our ENTERPRISE production series) exhibit better than ±0.9% uniformity in excellent agreement with the modeling.

RDRs have inherent advantages in hydrodynamic symmetry and flow dynamics that enables growth to be laterally uniform, abruptly switchable, and robust against variations in process parameters. In addition to the excellent results, our system meets the need of device manufacturers. Specifically, cost effective production scale manufacturing requires (1) scaled up systems that can deposit uniform layers over multiple wafers, (2) sophisticated process control that enables flexible and predictable growth of the complex semiconductor alloys required by advanced microelectronics and photonic devices, and ultimately (3) integration of such production scale reactors with integrated manufacturing lines and with industry standard cluster tools for automated manufacturing.

TABLE I:	Grown Materials
III-V	GaAs, AlGaAs, InP, InGaAP, InGaP, InSb, GaN, etc.
II-VI	ZnSe, CdTe, HgCdTe, ZnTe, CdZnTe, CdSeTe
IV-IV	SiC, Diamond, SiGe
OXIDES	YBCO, BaTiO, MgO_2, ZrO, SiO_2, ZnO, ZnSiO
METALS	Al, Cu, W

In order to meet the extensive needs of the diverse device and material markets, we have developed the cutting edge technologies necessary to fabricate complex structures. These technologies include development of an engineered fluid dynamical reactor, complex gas handling schemes with precise pressure/flow control. These properties are needed to produce films of uniform thickness and composition, interface abruptness of an atomic layer, and sharp depant and alloy transitions. Figure **1b** shows an example of the sharp, repeatable interfaces achieved. Because of its well defined fluid flow and heat transport characteristics, as shown in figure **2a** and **2b**, a rotating disk reactor is ideally suited for flexible, intelligent manufacturing of complex ternary and quaternary *CS* materials. The symmetric design and stainless steel construction of the EMCORE reactor is compliant with MESC standards and is particularly well suited to the implementation of non-instrusive optical in-situ monitors for control. Further, the sharp temperature gradients associated with the flow dynamics of the RDRs minimize particle problems through the well known thermophoesis effect[2] . We have combined these system features

[1] C. Biber, et. al., J. of Crystal Growth, 123 (1992) p.545-554; M.A. McKee, et. al. J. Elec. Mat. 21 (3) (1992), p.289-292, W.G. Breiland and G. Evans, J. Electrochem, Soc. 138 (6)(1991), p1806-1816, G.S. Tompa, et. al, J. Crystal Growth, 93 (1988) p.220-227.

to produce the highest quality materials. RDRs have been successfully applied to many material systems, as listed in Table I.

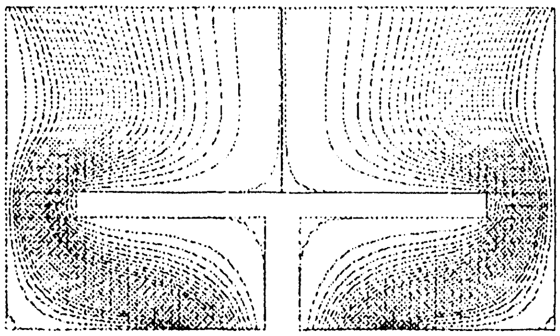


Figure 2(a) Contours of Stream.

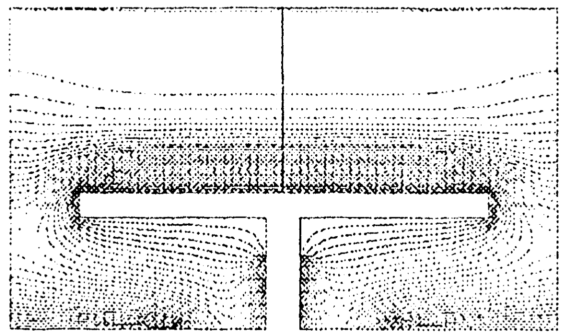
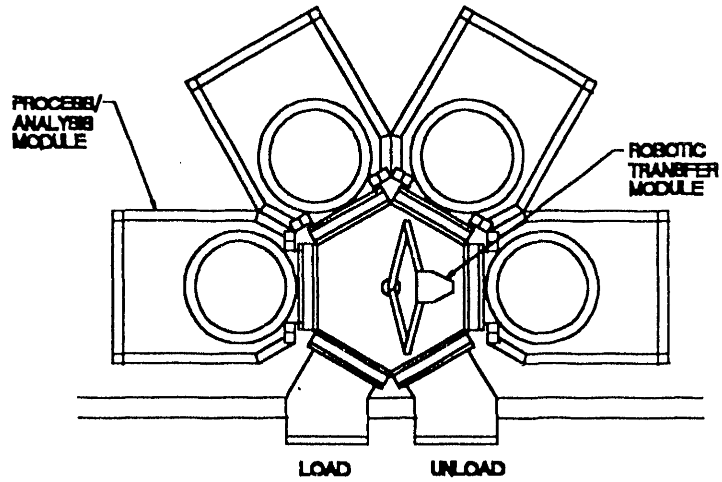


Figure (b) Contours of Temperature.

By forming a common, generic **MESC** compatible platform for compound semiconductor production we have developed a true production tool for these strategic materials, which does not presently exist. Our reactor platforms are compatible with both platter or wafer transfer. The wafer transfer is most economical when growth times are greater than ~30 minutes. Alternatively, when the growth times are short, robotic wafer transferring systems and even single wafer processing becomes more economical. Our cluster tool platform, which is shown in figure **3b**, alongside a platter transfer system (figure **3a**) can be used as an integration platform for attachment of established Si process modules and analytical stations. The cluster tool platform can be expanded from 4 to 8 facets, upon which additional modules or loading/unloading modules can be mounted. The central robot can transport wafers or platters up to 8" in diameter from any location in the system to any other location.

A sophisticated, real time hierarchael control system, which features a dedicated PLC to control process steps, a proprietary PC based spreadsheet to schedule run parameters, and a dedicated technology display system continuously depicting and monitoring the system status with data logging, is used to control our system. Our present interactive real time control platform is a stepping stone needed for future intelligent systems operation; including establishment of statistical databases, incorporation of modeling processes, and the integrated operation with Computer Integrated Manufacturing (**CIM**) factories. The capability of making a continuous recording of the growth history of a semiconductor structure reduces costs by eliminating the need for downstream testing of every wafer and by providing information of direct use for quality control charts, and failure-mode diagnosis.

An important concern for the compound semiconductor industry is its environmental impact. The high utilization efficiency makes this system most ideal for use of alternative and highly expensive reactants. In addition to efficiently consuming reactants (which are generally highly toxic), a well proven effluent scrubbing system is used. This toxic gas adsorption system reduces the waste reactants to stable materials suitable for commercial disposal services. With high reactant efficiencies and short cycle times between growths using the loadlock; the cost per wafer is found to be dramatically less than in competitive system technologies. EMCORE has developed a cost of ownership model which encompasses



3b) Cluster Tool Configuration

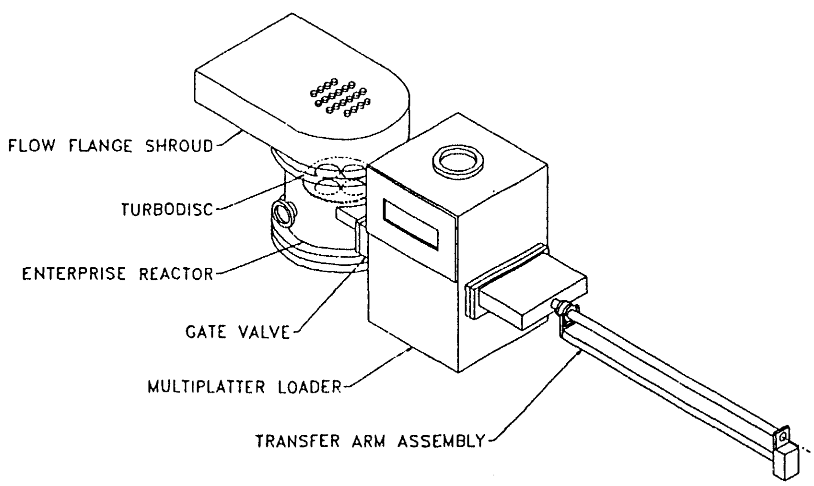


Figure 3a) Platter Transfer Configuration

facilitation, system cost, operational costs, projected throughputs and maintenance. This established spreadsheet program is an invaluable tool in choosing an optimum processing technology and will be reviewed. Statistical operational data in combination with prescribed component maintenance determines preventative maintenance schedules. Key inputs are capital costs, throughput, up-time, process, consumables, and gas utilization. Complete production cost accounting is necessary for profitable production.

In closing, we have produced a complete methodology for MOVPE manufacturing systems. The needs for high throughput, low maintenance and a reproducible process are addressed by a large RDR platform with robotic wafer handling and MESC compability.

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