

# THE CRITICAL ROLE OF PROCESSING IN LEADING-EDGE PRODUCT CAPABILITY

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Processing may be defined as all manufacturing steps that turn a raw material into a useful product. To remain a world leader in the information movement and management (IM&M) industry, AT&T must continue to develop world class processing capabilities to fabricate products and systems that can be used anywhere in the world, and that are more flexible, cost effective, and user-friendly than its competitors'.

## Introduction

AT&T's integrated manufacturing capability lets it couple manufacturing processes tightly with product designs and service needs. It gives the company early access to powerful new devices and systems, as well as to cost savings through economies of scale.

An essential element in successful manufacturing is efficient, high-quality, and responsive materials processing. The processes used to manufacture devices and components for modern electronics systems are complex and demanding; they must be robustly designed so that moderate changes in process variables will not result in catastrophic changes in product quality.

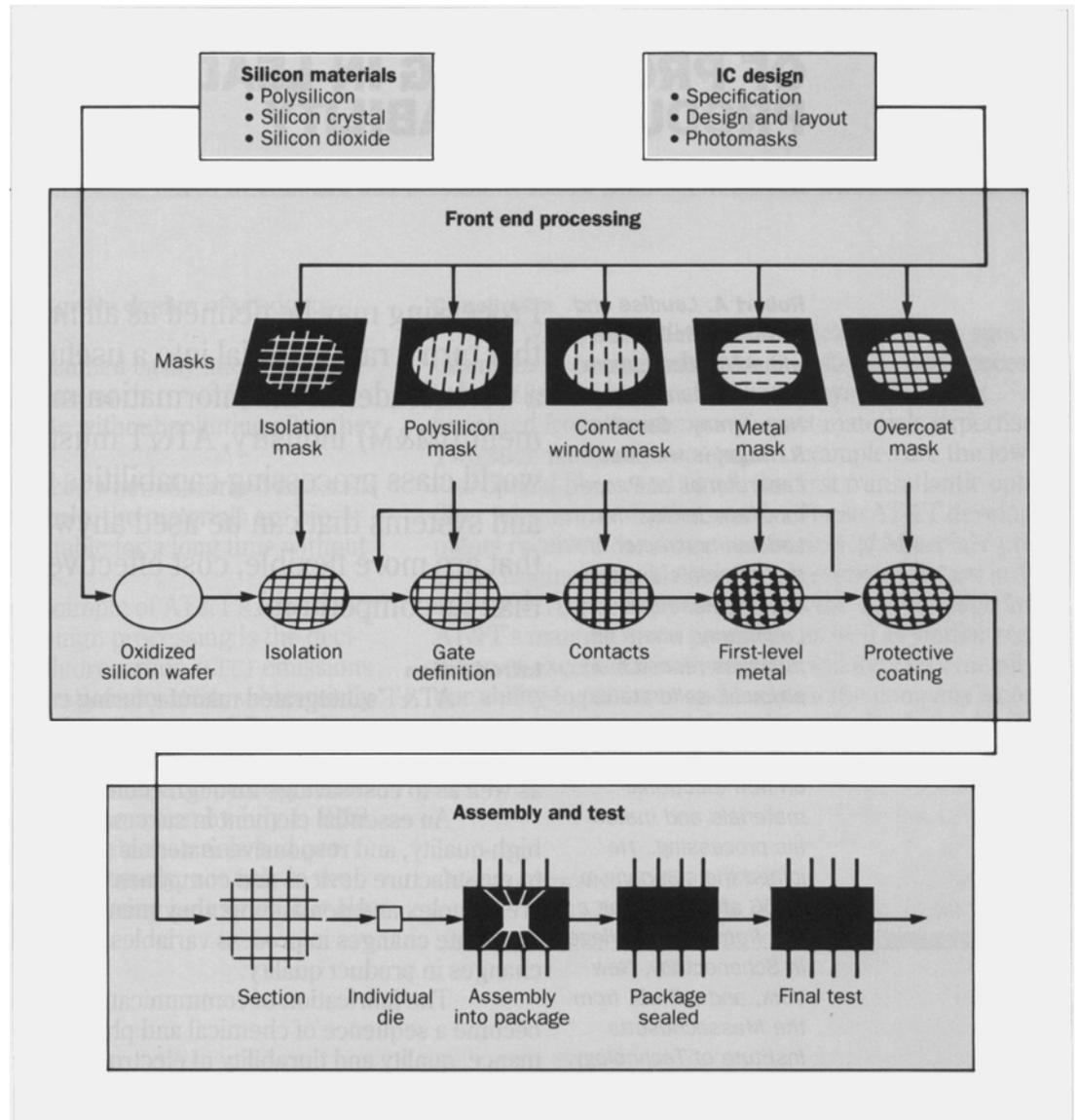
The fabrication of communications equipment has increasingly become a sequence of chemical and physical processes. The performance, quality and durability of electronic equipment depend critically on the materials and processes used in their manufacture.

Integrated circuits, optoelectronic devices, optical fibers, printed circuit boards, hybrid interconnections, and wires and cables are among the principal building blocks of AT&T's IM&M systems. They provide the foundation for the company's services to its customers. These components and devices are key to AT&T's products, making possible the cost and feature differentiation vital to success in the marketplace. Processing and assembling them are the value-added tasks of our factories.

Although it is clear that the quality of a product can be no better than the quality of the materials that go into it, it is also true, though less evident to the non-specialist, that a product's quality depends critically on manufacturing processes.

AT&T's factories use a great variety of processes, ranging

**Figure 1. Process sequence for manufacturing a moderately complex silicon device. A series of intricate steps assures material purity, precisely positioned active elements, and deposition of small numbers of atoms to create transistors.**



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from integrated circuit (IC) fabrication through wire drawing. They include extruding insulation and sheathing conductors; making optical fiber preforms, then drawing and coating the fibers; and cabling, molding, plating, laminating and assembly. Hundreds of extrusion and molding machines are in constant use, as are scores of preform lathes, fiber draw towers, laminating presses, plating tanks, etching tanks, chemical vapor deposition chambers, ion implanters, plasma processors, molecular beam epitaxy (MBE) systems, and other processing machines.

Recent materials processing accomplishments at AT&T include the invention and rapid transfer to the manufacturing floor of the processes needed to produce the optical fiber used in the first transatlantic and transpacific optical communications systems. Both systems required optical fiber that would meet unprecedented demands for high strength, high bandwidth, low signal loss, and low cost. At the same time, high-reliability systems had to be designed to guarantee that they will function unattended at oceanic depths for at least 25 years.

The fiber-drawing process used by AT&T for

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these systems calls for precise control of fiber's chemistry and dimensions. The process includes in-line coating and curing of a protective plastic jacket at a speed of 3 meters per second (3m/sec), or about 6.7 miles per hour. Similar achievements are required to produce the lasers, detectors and other components in submarine cable repeaters. Among the daunting materials and process challenges that had to be faced was the need to assemble components and devices able to withstand the rigors of being installed on the ocean floor, then protecting the equipment from the hostile environment.

Optically integrated devices, modulators and other increasingly sophisticated optical components have been developed to meet market demand for higher bandwidth at lower cost. The economic viability—even feasibility—of this new generation of optical components will be determined largely by processing capabilities. These capabilities include a number of generic processing issues that cut across product lines and detailed processing procedures, and constitute core competencies.

Packaging, interconnection, and reliability considerations also cut across product lines. Materials processing and device packaging often represent a large portion of a system's cost: as the scale of integration increases, interconnection costs increase more rapidly than device costs. Novel interconnection techniques and materials now being investigated may radically reduce these cost trends, giving a substantial advantage to organizations that apply cost-effective solutions to packaging and interconnection problems.

Reliability is at the root of customer satisfaction and cost control. Quality algorithms, root cause analysis and failure prevention are now being applied to processing, as well as to the analysis of field failures. The result has been a remarkable improvement in processes and the resulting products.

Another challenge is driven by worldwide environmental concerns and the added social, political and economic costs of handling, processing and disposing of dangerous materials. It has created a new factory ethic:

Use only benign materials, and process those materials with negligible harm to the environment. Work already under way shows promise of providing environmentally benign processes in the fabrication of electronic and optoelectronic devices.

In this issue of the *Technical Journal*, AT&T experts present a series of papers that address subjects especially germane to the major leading edge materials processing considerations mentioned above. The papers address recent accomplishments and present problems, and lay out a map for the future of materials processing in the 1990s. As a prelude to these papers, it is useful to discuss some categories of AT&T products to illustrate the way processing relates to product capabilities, especially for bellwether products that incorporate materials and processes that have been pushed to the limits of current knowledge.

#### **Silicon Integrated Circuits**

The fabrication of microelectronic devices requires hundreds of process steps, carried out in sequence, to yield planar circuits with millions of elements on an area the size of a fingernail. The elements are intricately and perfectly interconnected. Each step is a chemical or physical process that must be precisely controlled. Silicon is "pulled" from the melt, then sliced and polished to produce wafers four to eight inches in diameter that are ultrapure single crystals. The fabrication of microelectronic devices requires selective diffusion of tiny amounts of impurities into specific regions of semiconductor substrates to produce the circuit's transistors. These regions are then combined in successive layers of conductors, such as polysilicon or aluminum, and insulating films of silicon dioxide or silicon nitride. The successive layers are patterned through a series of photolithographic steps. A complex device may contain as many as twenty layers of materials, and each layer must be patterned accurately. The materials must be precisely formed with extreme care and purity.

Figure 1 shows the manufacturing sequence of a

**Table I. Annual AT&T Materials Usage Of Wire and Cable**

	Dollars (Million)	Pounds (Million)
Copper	260	250
Polyvinyl Chloride (PVC)	32	53
Polyethylene	45	75
Filling Compound	12	30
Fluoropolymers	6	1

moderately complex silicon device. The wafer is first oxidized to form a thin and perfect film of silicon dioxide. In the first patterning step, the area of each chip is defined and electrical isolation is provided. The isolated areas are then doped with small numbers of atoms (a few parts per billion) to define the electrically active transistors. Next, a conductor—usually polysilicon—is deposited and patterned to connect the first transistor cells, an insulating layer is deposited, and so on.

In addition to materials used in the device structure itself, other process chemicals are required during its fabrication. Polymers (“resists”) sensitive to ultraviolet (UV) light radiation are used in the patterning step. The polymers must have precisely controlled composition and molecular properties. They must also be ultrapure, with total ion contamination below 30 parts per billion. Resist polymers have to be extremely sensitive to the patterning radiation. At the same time, they must form tough, unreactive protective layers that remain stable during the ensuing deposition, diffusion and etching steps. Other chemicals used include etchants, cleaning reagents, resist developers and resist strippers. This patterning process is repeated many times.

After final testing, the device is packaged, usually in a very pure polymer composite, to make it easy to handle and to protect it from the outside environment. With several hundreds of these devices obtainable per wafer, each can be worth tens or hundreds of dollars. This makes the value of a processed wafer very high, even though the cost of its raw materials is only a few dollars. It is the intervening, complex process that

results in the enormous addition of value.

Processing optoelectronic components and gallium arsenide electronic circuits is similar in many respects to silicon processing, although III-V compounds are more difficult to process than silicon, and extremely complex structures and properties are required for optical devices. Generally, gallium arsenide components benefit from techniques developed in silicon processing. In some circumstances, however, new and more exotic measures are needed. Thus, MBE and other leading edge methods are expected to become major contributors to non-silicon device manufacture.

#### **Wire and Cable**

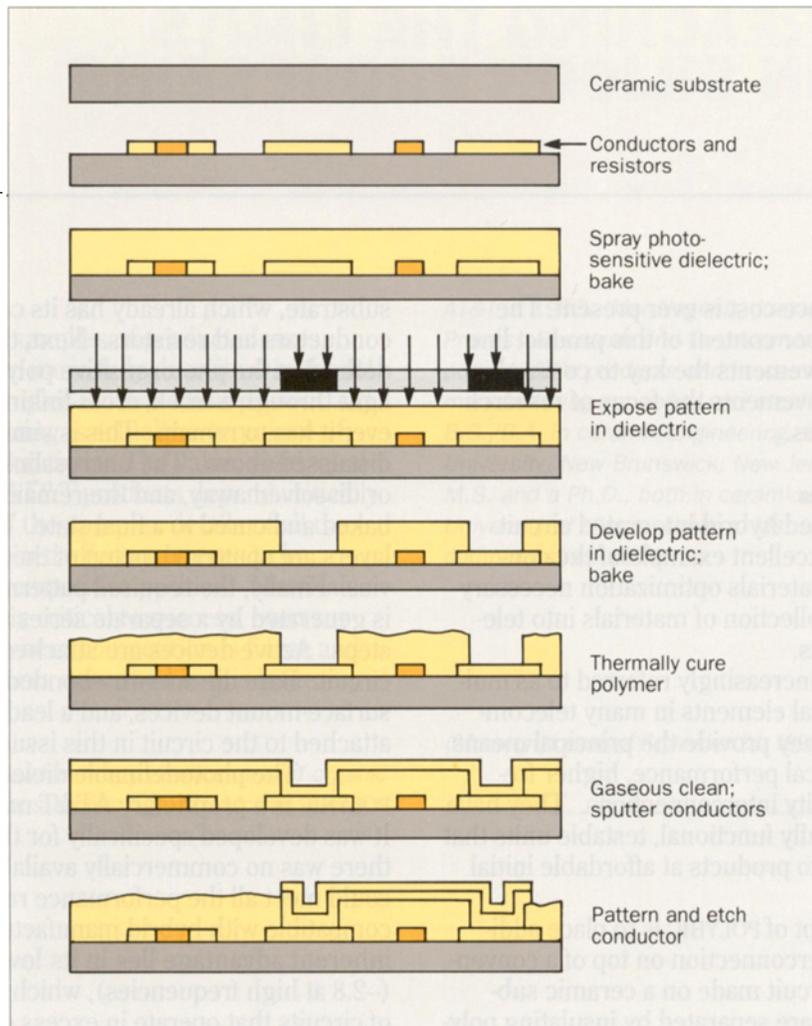
Wire and cable are among AT&T's most materials-intensive products. The product line includes diverse offerings designed to fulfill many different customer requirements. For this discussion, the product line may be divided broadly into *copper-based* and *glass-based* cables.

The copper product line is manufactured at AT&T's Atlanta, Omaha and Phoenix Works. The product dates back essentially to the company's beginning, when signals were carried over uninsulated wire or, where necessary, textile-insulated wires and cables.

In current usage, all insulating and jacketing materials are made of synthetic polymeric materials, most commonly polyethylene. AT&T uses more than 75 million pounds of this polymer each year (see Table I).

The properties of polyethylene are almost ideal for electrical insulation. In products that must be fire-resistant, polyvinyl chloride (PVC) is used. For even more demanding applications, such as cable placed in air plenums, a variety of fluorocarbon polymer is employed.

In all cases, the production method is similar. A copper rod is drawn into wire and annealed. The wire is then preheated before it passes through an extruder crosshead, where a tube of hot, often color-coded, plastic is formed and drawn down onto the wire. The insulated conductor is then cooled and spooled. This continuous



**Figure 2. Schematic cross-section of the POLYHIC fabrication process using PHP-92, an AT&T proprietary polymer that defines vias photolithographically.**

process normally runs at speeds around 30 m/sec ( $\approx 67$  miles/hour). Wires from the spools are combined to form cable pairs and cable cores that are filled, armored and jacketed in a second extrusion process.

The glass-based fiber made at the Atlanta Works was first commercialized in the late 1970s. In current processing, a glass preform about one inch in diameter is first prepared with the appropriate refractive index gradient across its diameter. The preform is usually prepared by modified chemical vapor deposition (MCVD), described by Walker's paper in this issue. Next, it is heated and drawn down to 125 micrometer ( $\mu\text{m}$ ) fiber at about 6 m/sec (14 miles/hour). The fiber passes through an in-line coating cup and receives a  $62.5\mu\text{m}$  coating of low-molecular-weight polymer that is cured to

form a protective coating as the fiber passes through a UV radiation chamber. The fiber is wound onto a reel and subsequently assembled into one of a variety of cable designs. Finally, a plastic sheath is extruded to protect the cable.

Because of their relatively high installation cost, wires and cables are designed to operate unattended for a long time. To this end, long-lived organic materials are used to optimize long-term performance in environments that are often hostile. These materials are continually improved as new understanding of their properties is developed.

The basic technology for the copper product is mature, but development in the technology of glass fiber systems continues. As in all products, the desire to

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improve quality and reduce cost is ever-present. The high material and low labor content of this product line makes processing improvements the key to cost reduction, making those improvements the focus of research and development activities.

### **Hybrid Integrated Circuits**

The polymer-based hybrid integrated circuit (POLYHIC) provides an excellent example of the controlled processing and materials optimization necessary to integrate a complex collection of materials into telecommunications products.

Hybrid circuits, increasingly referred to as multichip modules, are critical elements in many telecommunications systems. They provide the principal means to achieve higher electrical performance, higher frequency, and higher-density interconnections. They have the advantage of being fully functional, testable units that can be turned quickly into products at affordable initial manufacturing costs.

The basic concept of POLYHIC is to place additional layers of metal interconnection on top of a conventional thin-film hybrid circuit made on a ceramic substrate. The metal layers are separated by insulating polymer dielectric layers and interconnected through openings (vias) in the polymer.

POLYHIC was developed jointly at several AT&T research and development and manufacturing locations. Early on, it was decided to use a photosensitive polymer in which the vias can be defined photolithographically. This lowered costs by eliminating many manufacturing steps that otherwise would be required if a separate photoresist were used. Another key factor in the success of this technology was to draft a written, agreed-on, stable set of material requirements that would focus development efforts.

Figure 2 shows the steps involved in making a single POLYHIC layer of interconnection. First, the liquid polymer is sprayed and baked dry on top of the

substrate, which already has its complement of thin-film conductors and resistors. Next, the pattern of vias is defined in the photosensitive polymer by shining UV light through a mask, cross-linking the polymer wherever it has to remain. This is similar to the resist process discussed above. The uncrosslinked vias are developed, or dissolved away, and the remaining polymer is further baked and cured to a final state. Then, conducting metal layers are sputtered on top of the polymer and into the vias. Finally, the required pattern of the top conductors is generated by a separate series of photolithographic steps. Active devices are attached to make a working circuit. Bare die-and-wire-bonded devices, packaged surface-mount devices, and a lead frame can be seen attached to the circuit in this issue's cover photograph.

The photodefinable dielectric polymer used in POLYHIC is a proprietary AT&T material known as PHP-92. It was developed specifically for this application because there was no commercially available material known that could meet all the performance requirements and still be compatible with hybrid manufacturing processes. PHP-92's inherent advantage lies in its low dielectric constant (~2.8 at high frequencies), which permits construction of circuits that operate in excess of 2 gigahertz. The material absorbs comparatively small amounts of water and is relatively unaffected by the water it does absorb. This leads to very stable dielectric properties and stable characteristic impedances for sensitive circuits. PHP-92 also has good photodefinability, or resolution, allowing the printing of small vias.

One-layer POLYHICs (1 polymer layer, 2 metal layers) have been manufactured routinely at the AT&T Merrimack Valley Works for several years. The product is attracting a growing number of customers within and outside the company. Much of the demand is for 2 or more polymer layers (3 or more metal layers) for very dense, highly functional circuits. Two-layer POLYHICs are currently being introduced into manufacture, and higher polymer layer counts will soon be available.

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**Conclusion**

The foregoing examples of product classes, together with others, are more fully described in the following papers. The examples illustrate that present and future AT&T manufacturing is actually a sequence of materials processing operations. The value, yield, quality and performance of AT&T products depend critically on our understanding of the complex details of all the steps. Dogged and inspired effort continues to be required to maintain a competitive position. Materials and process leadership is critical to success, even survival, in a marketplace where competition is fierce and well advanced in every area described in this issue.

Biographies (continued)

Laboratory, he manages research into applications of organic materials in communications technology. Mr. McCall joined

AT&T in 1953. Ms. Nagel is director of the Manufacturing Process Research and Development Laboratory, which supports AT&T's products and processes to assure world class manufacturing capability and excellence. Ms. Nagel has a B.S./B.A. in ceramic engineering and liberal arts from Rutgers University, New Brunswick, New Jersey. She also received an M.S. and a Ph.D., both in ceramic engineering, from the University of Illinois, Urbana. Ms. Nagel has been with the company since 1972.

*(Manuscript received September 24, 1990)*

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