very day, more and more applications use photonics components to enhance performance, reduce size, or reduce cost. The demand for volume deployment of photonics components has soared, and with it the need to effectively package these unique technologies in a reproducible and cost-effective way. In the microelectronics world, the term “packaging” typically refers to the encapsulation of the componentry into a form that can be easily connected into a circuit, while protecting it from assembly and test handling damage, as well as the environment in which it will eventually be used. In the photonics world, packaging often combines the need to provide not only for electrical connection, mechanical support, and thermal management, but also, more critically, an optical connection that is highly directional in nature and requires extremely precise control of positional tolerances between components. The packaging of photonic components represents unique requirements and challenges, but following a few rules of thumb about design and manufacturability simplifies the process.

Photonic components can be classed as active or passive (see table). Active devices are those requiring some sort of electrical connection. A common type of active device performs some sort of optoelectronic conversion, either converting electricity into light, as in a diode laser, or converting light into electricity, as in a photodiode (see oemagazine, August 2001, page 34). Other types of active devices either manipulate the signal (modulate, amplify, or attenuate) or change its direction or magnitude (switching, attenuation, scanning).

Passive devices are those that do not have any electrical connections. They simply filter or route the signal, based on wavelength, intensity, or polarization. In other words, the light passes through them without any electrical energy being added or extracted from the device. These devices typically have multiple fibers going into and/or out of them.

Both of these classes of devices share many common packaging requirements; yet each has some unique
ones as well. It is easiest to distinguish these in the context of the optical, mechanical, electrical, and thermal design considerations.

**Design Requirements**

The packaging design must be driven by the design requirements of the component. Not surprisingly, there are tradeoffs involved in the packaging design process, so it is important to understand the requirements.

The most critical aspect of any photonics package by far is the optical connection. Unlike electrical connections, these have some very interesting and challenging characteristics. Optical connections require extremely precise alignment and are highly sensitive to relative motions between the device and the optical components, which typically include some sort of lens and a fiber. Displacements on the orders of fractions of a micrometer can render the component useless (see figure B). Passive devices often have many couplings, further complicating the assembly process.

The ability to effectively get light from the device into a fiber is characterized by a parameter known as coupling efficiency. To achieve good coupling efficiency, it is necessary to shape the beam to match the mode of the beam emitted by the device to that of the fiber. Diode lasers, for example, often emit high elliptical beams. Efficiently coupling these beams into a circular fiber core requires special lenses to reshape the beam. In general, high coupling efficiency (or low loss) is a property even more important for passive devices.

Many optoelectronic devices are sensitive to optical feedback, commonly caused by back-reflection from the coupling optics. Specialized coatings, angle-cleaved fiber, or optical isolators can minimize or eliminate this problem.

Stabilizing many active devices requires continuous monitoring of either power intensity or wavelength, requiring additional electronic and/or optical components (e.g., a monitor photodiode, etalon filters, etc.). This adds to the complexity of the device, and these typically require precise alignment/placement as well.

As mentioned above, only active devices require electrical connections, often to both the device itself and the cooling and/or monitoring elements as well. High-speed devices are currently running as fast as 40 GHz. At these microwave frequencies, the wiring tends to act as an antenna and can induce noise. Thus designers must pay particular attention to the design of the wire-bonding or die-bonding connections, as well as packaging shielding.

For both active and passive devices it is important to manage the thermal dissipation within or across the device because thermal gradients will typically lead to misalignments and reduced coupling performance, or degradation of the device itself. For active devices, the heat generated within the package is of primary concern. Active devices are typically cooled using thermoelectric (TE) cooling elements (see OEMagazine, M arch 2001, page 34) soldered to the package base, which is eventually mounted to an external heat sink.

Many fiber-optic components go into underground or undersea optical networks, so device reliability is paramount. Packaging design and execution can have an important effect on device lifetime. To design for reliability, avoid using epoxies that produce curing or outgassing residues that can affect the devices or the optics. Telcordia specifications, the industry standards for environmental resistance, are very stringent. Component performance and hermetic seal integrity must be tested in the face of mechanical shock, vibration, and thermal cycling over a range as high as 100°C. When designing packaging for these components, it is important to pay particular attention to the quality and accuracy of mechanical attachments in order to maintain optical, thermal, and electrical connections during these tests.

**The Manufacturing Process**

A back-end packaging process can typically be broken down into a series of major steps: preassembly device test and sort, package assembly, optical assembly (or “pigtailling”), sealing, and final test and qualification (see figure C).

The first step is preassembly device testing and sorting, in which initial performance characterization, inspection, burn-in, and sorting is done prior to assembly. To achieve high yields, it is important to devise appropriate methods.

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**Examples of different classes**

<table>
<thead>
<tr>
<th>ACTIVE DEVICES</th>
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<tbody>
<tr>
<td>Transmitters</td>
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<tr>
<td>Receivers</td>
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<td>Modulators</td>
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<td>Attenuators</td>
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<td>Switches</td>
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<tr>
<td>Amplifier Pumps</td>
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<tr>
<td>Semiconductor Optical Amplifiers (SOA)</td>
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<table>
<thead>
<tr>
<th>PASSIVE DEVICES</th>
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<tr>
<td>Wavelength Division Multiplexers/DeMultiplexers (WDM)</td>
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<td>Filters</td>
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<tr>
<td>Isolators</td>
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<tr>
<td>Couplers</td>
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<tr>
<td>Power Splitters</td>
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<tr>
<td>Arrayed Waveguides</td>
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<tr>
<td>Fiber Bragg Gratings</td>
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</tbody>
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**Figure B**

A plot of optical power as a function of position for a typical diode laser. This is known as the “spatial power distribution” of the device and indicates its sensitivity to misalignment.
for handling the devices, for example using submounts and specialized carriers.

The next step is package assembly—placing the components into a package or onto a submount prior to making the optical connection. Tolerances are typically in the 10 to 50 µm level for these types of placements, and automation systems with machine vision can ensure repeatedly high yields. Special attention should be paid in the design phase as to how the parts are to be handled and transferred to minimize damage.

Optical assembly comes next. The optical assembly requires extremely specialized submicrometer alignment and an attachment process that will maintain the alignment both during assembly and in the field. Active optical alignment, in which power throughput is monitored during this process, is often necessary to assure high yields. In some cases, however, passive alignment (no electrical or optical power coupling required) is adequate, depending on the device and performance requirements. Vision-assisted positioning systems can achieve passive alignments of 1 µm.

Any components must be hermetically sealed after alignment. For active devices or optical elements that are sensitive to moisture, this is often preceded by a bakeout, which reduces or even eliminates moisture and contamination. Bakeout is followed by a backfill with inert gases. Many passive devices are potted within an external cylindrical housing. Occasionally the hermetic seal is performed prior to the pigtailing operation.

Once the device is completed, a full characterization is performed. It is important to prevent handling damage at this point, so again it is important to design appropriate carriers and handlers to assure high yields.

The major challenges that are uniquely associated with photonics packaging relate to the extremely tight assembly tolerances and the difficulty of handling fragile fibers during a volume production process. In order to achieve and maintain alignment, it is important to pay special attention to the bond joints and joining techniques. Some processes, like soldering and laser welding, allow for post-bond adjustment to correct for shrinkage or bond-misalignments. Compensation offsets can minimize or eliminate bond shift. Epoxies lend themselves to shrinkage compensation, though they are typically not reworkable.

Another unique and highly challenging aspect of packaging photonics versus electronics is the fiber itself. Often during the manufacturing process, the fibers must be stripped, cleaned, and cleaved; coupled into light sources and detectors; fusion spliced, coiled, and uncoiled—all of which can induce breakage or defects that lead to low yields. Designing package and manufacturing flow to minimize handling is critical.

**lessons to remember**

First-generation optic components were designed to achieve high performance, not low cost. Today’s markets are demanding drastically reduced costs in order to prove the economic viability of bringing optical networks to the home, which makes packaging a critical issue for the telecom market in particular. Design for manufacturability and automation is essential for future generations.

Several lessons learned from the first-generation devices, along with some good common manufacturing sense, lead to the following design rules of thumb for new devices:

1. **Think standardization.** There are few standards out there—whenever possible, use off-the-shelf package bodies, fiber ferrules, and optical components.
2. **Consider handling issues early in the design phase,** especially when handling small optics and electrostatic sensitive devices (ESDs).
3. **Perform critical alignment/attachments outside the package** if possible. Working inside the package is like building a ship in a bottle.
4. **Think automation;** for example, put fiducial markings on the devices to assist machine vision systems.
5. **Put a handling fixture onto all components that need to be manipulated.** Prepackage or prealign subassemblies (fibers, optics, etc.) to facilitate rapid assembly and reduce the number of adjustments needed in any given process.
6. **Watch your tolerances.** The optics will eventually define how tight the assembly tolerances are, but there are design options that will make the assembly more forgiving while still maintaining device performance.
7. **Be alert to the relative motion of components.** Keep all critical components together on one submount if possible to avoid relative misalignments with temperature.
8. **Adopt solutions from the electronics and semiconductor industry.** These industries went through many of the same challenges early on, and some of their solutions apply readily to photonics.

The very sensitive assembly tolerances, along with the fragility of fibers and optical elements, combine to make photonics packaging a much more difficult task than their purely electronic counterparts. However, many principles for design, manufacturing, and automation can be applied from the electronics and semiconductor industries to help next-generation devices achieve order-of-magnitude lower costs. 0E

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**Fiber-Optic Component Packaging Process**

- **Device Pre-test and Inspection**
- **Electro-mechanical Assembly**
- **Optical Assembly/Pigtailing**
- **Bake and Seal (if applicable)**
- **Final Test/Characterization**

**Figure C**

The manufacturing process for photonic components.

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