Disposable fiber devices are key to minimally invasive medical applications

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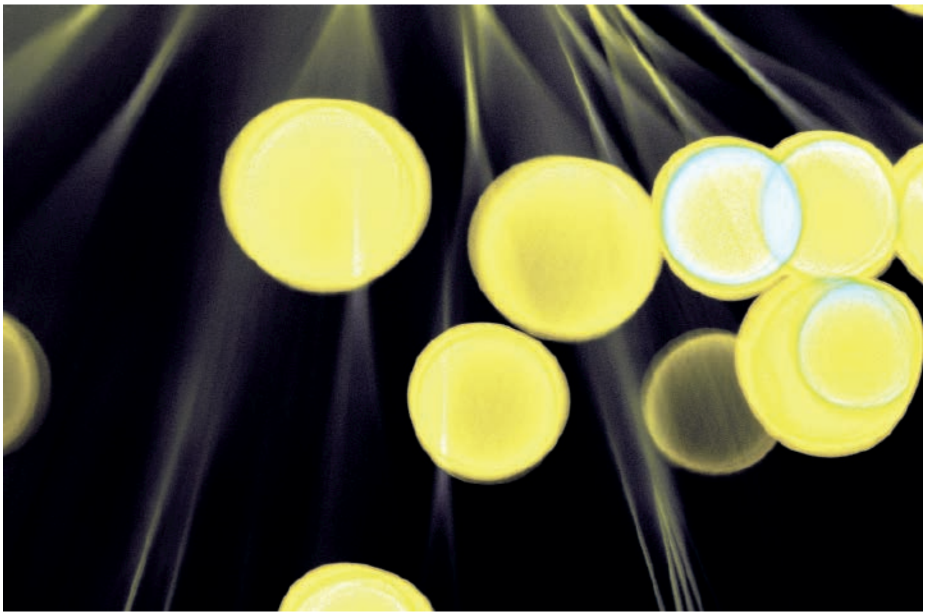

Many laser and LED based medical procedures require efficient delivery/retrieval of light via an optical fiber – a highly specialized discipline – creating a growing need for economical (i.e., disposable) fiber-coupled sub-systems where all the optical components are precision aligned and pre-assembled.

Fiber Delivery – Key to Minimally Invasive Procedures

Advanced light sources such as lasers, LEDs, and supercontinuum devices, are increasingly used in medical therapeutic procedures. These include applications where the light is used as an interventional tool, e.g., for cutting tissue, or for imaging to assist in a remote procedure. Where the light must access inside the body, fiber optics are typically used and are compatible with the growing demand for minimally invasive procedures performed through a device such as a laparoscope or catheter. The advantages over conventional surgeries are reduced patient discomfort, less risk, and lower costs.

Efficiently coupling light into a fiber optic is a specialized optomechanical task with many potential pitfalls in practice. For example, the light has to be focused into a fiber core that may be tens of micrometers or less in diameter, moreover in a way that maintains this precise alignment during actual use by a surgeon or medical technician. As a result, most medical tool manufacturers outsource this task. So rather than purchasing separate components, e.g., focusing/coupling optics, fiber, distal (output) optics, they specify a device where are all these components are pre-aligned and assembled and then thoroughly tested and certified/documented. They are usually destined to be disposable to avoid cross-patient contamination, so they must be designed for simple plug-in optomechanical registration with the laser source. Moreover, low cost is invariably as important as the performance metrics.

Three very different applications illustrate the breadth of applications where fiber optical systems now play an enabling role.

Laser Lithotripsy

One of the oldest fiber delivered applications is lithotripsy – used to break up stones (crystalline mineral aggregates) in the kidney, bladder, urinary tract or gall bladder. Here, pulses from a laser are delivered by fiber within a flexible tool such as an ureteroscope. The short (nanoseconds) high-energy pulses are absorbed by the target stone. This creates shock waves in the rigid stone that shatter it into smaller pieces that can then be passed harmlessly in normal urine flow. Originally, a pulsed dye laser was used, but for the past two decades, the laser of choice is a Holmium:YAG laser, although newer mid-infrared lasers such as the thulium fiber and erbium laser sometimes appear in this application.

This application does not require a tight focus so a multimode fiber is used. However, because it involves high pulse energy and high peak power, a key requirement is high optical throughput with low losses. In particular, it is important to avoid power leakage into the fiber cladding, so a precise concentric coupling of the laser into the fiber is critical. (Coherent draws fibers of this type from a special application-specific pre-form.) The fiber is tested and certified for damage threshold and for bend radius. Loss as a function of bend is also measured. Two different tips can be attached to support surgical variations, these are the ball form and straight tip – see figure. After assembly, the system is further tested (i.e., both functional and environmental tests) before shipment to the medical system manufacturer.

Ablation of Brain Tissue

The use of laser light to selectively ablate small amounts of brain tissue – laser neuroablation – enables the treatment of cancer (e.g., glioblastoma) and epilepsy. Neuroablation is used as an alternative to open surgery (i.e., craniotomy) and cryosurgery techniques. It is normally conducted under live, high-resolution MRI imaging to enable extreme spatial accuracy, often by using robotic technology. Here the main advantage of fiber delivery is to enable incorporation into a small diameter surgical tool that minimizes the trauma to the skull and more importantly, minimizes any disruption of the intervening brain tissue that must be penetrated to reach the target location. Since the usual goal is to thermally denature or coagulate brain tissue rather than vaporize it, typically a moderate (<20 W) power continuous wave laser at a wavelength of 980 nm (diode laser) or 1064 nm (Nd:YVO_4.) is deployed through the fiber.

From a fiber system viewpoint, there are unique criteria that must be met. First, the system must be immune to damage and movement by the high magnetic fields used in MRI – at least a few Tesla at the treatment focus. However, given that the treatment is thermal, it is

Figure. OEM fiber systems can be terminated with a variety of different tips and optical shapes.

also critically important to closely monitor and control the temperature. The high magnetic fields preclude the use of thermo couples using metal wires, so the temperature is monitored optically, via a second fiber within the tool. The temperature is then controlled using flowing gas (CO_2) cooling of the tip.

In this application, the assembled probe is rigid or semi-rigid, so bend radius and bend losses are not important parameters. Two different distal tip geometries are used in Coherent fiber assemblies in order to support various procedures: a side-fire tip that enables highly localized tissue damage, and a diffuse tip that supports isotropic tissue destruction around the tip. In its final assembled form, the medical tool manufacturer then encapsulates the tip with a strong, inert and transparent material such as synthetic sapphire.

Optical Coherence Tomography

Optical coherence tomography (OCT) is a clever method for obtaining three-dimensional images. Broadband light is directed into tissue and the back-reflected light interferes with light from a reference surface. The distance to the reference surface (or the tissue) is steadily incremented and because the light is deliberately incoherent, interference only occurs when the path difference of the two light paths is close to zero.

OCT has remained a niche imaging technology, with the notable exception of ophthalmology, but there is growing interest in using OCT to perform imaging in catheter-based tools for arterial and cardio procedures. This enables the surgeon to make key decisions in real time, such as where to place a stent or where to ablate tissue.

Coherent supports the medical tool industry with two different system architectures for catheter OCT imaging: a dual fiber version where the broadband illumination and the return (i.e., back reflected) light are carried in two separate fibers, and a single fiber format where one fiber performs both functions. As with lithotripsy, minimum bend radius is a key characteristic. The distal tip is usually either an angled ball lens or a prism. In operation, this tip rotates as it slowly moves through the vessel, taking a succession of image slices in real time.

Summary

In summary, there is a growing demand for minimally invasive surgical techniques that maximize quality of care while minimizing costs. Optical fibers play a critical role in many of these procedures, where the technology and market realities have converged into a demand for pre-aligned fiber optical systems that are disposable and configured for easy integration into these modern surgical tools.

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