Optical fibres are the foundation of the modern digital society. Since the first commercial cable was laid for the Dorset police in 1975, fibre optic communications has dominated telecommunications with estimates of around 325 million kilometres of fibre now being sold across the world every year.

The optical fibres in cables consist of thin strands of glass (around 125 micrometre diameter) surrounded by a thin polymer coating (around 250 micrometre diameter) and thicker protective layers. These outer layers protect the fibres when they are in place and include, in some cases, metal armour to prevent external damage, for example from seabed disturbances and sea life. However, the thin central glass strand is the important part for transmitting light. These solid glass strands transmit light via total internal reflection, which occurs at the interface between two materials of differing refractive index. Light approaching the boundary is totally reflected for all incident angles below a specific value (the critical angle). In the case of fibre optics any light that enters the fibre at or below this angle will be totally internally reflected along its length.

While ubiquitous, these solid-core fibres (essentially as first envisaged by the late Professor Sir Charles Kao KBE FREng FRS in the 1960s) have limitations. For example, the glass makes the light travel 30% slower than in air or a vacuum: this is how lenses bend rays of light and why solid fibres work at all. Additionally, light travelling in solid glass leads to other unwanted effects, in particular so-called non-linear effects that cause the light to change its wavelength. In a system with closely packed wavelength channels these non-linear effects ultimately limit the achievable data rate of above 100 terabits per second.

When looking at their use for higher power laser delivery, such as for cutting and welding metal, solid fibre can become damaged as the power of the light increases. A very small amount of light is absorbed and scattered by the silica, at kilowatts of power, this small amount causes damage to build up and can result in complete destruction of the fibre.

Given the limitations of existing solid glass fibres, it has been no surprise that many research groups have begun developing and deploying a new generation of optical fibres with air rather than glass cores. This new approach is called hollow core fibre optics.

HOLLOW CORES IN USE
Hollow core fibres are at the cutting edge of fibre optic technology, currently in development and, as a technology, are in their infancy. However, this has not stopped their rollout into applications previously dominated by solid fibre optics.

One of the biggest fibre optic markets is the telecommunications industry and it is an area where innovative new fibre designs can have great impact. A significant amount of the research and development has focused on this market with the goal of developing a low transmission latency, high bandwidth, low-loss hollow core fibre. There have been considerable advances in fibre performance and data transmission experiments over recent years, with key demonstrations of these characteristics. Data rates of more than 50 terabits per second have already been transmitted over lengths of hollow core fibre, illustrating their potential for high-speed communications.
HOLLOWING OUT A FUTURE IN FIBRE OPTICS

Hollow core fibres are higher than the best solid silica fibres. However, recently the University of Southampton announced that it has produced a novel hollow core fibre design with a record low loss of 0.13 dB/km with clear scope for further improvement – at least theoretically to values well below 0.1 dB/km, which is the loss for silica fibres.

Beyond telecommunications, hollow core fibres are also being applied to various sensing and laser applications. They offer a range of benefits for bandwidth and capacity data communications. Development of a fibre with a signal attenuation below that of current solid silica fibres (0.2 decibels per kilometre (dB/km)) would allow for increased repeater spacings and improved system capacity. The lowest attenuation levels currently reported for a hollow core fibre are higher than the best solid silica fibres. However, recently the University of Southampton announced that it has produced a novel hollow core fibre design with a record low loss of 0.13 dB/km with clear scope for further improvement – at least theoretically to values well below 0.1 dB/km, which is the loss for silica fibres.

HOW DO THEY WORK?
Hollow core fibres appear very similar to existing optical fibres, they are made from a thin strand of glass of around the same thickness. However, whereas solid silica fibre cores are made from solid silica, a hollow core fibre has a core formed by microstructured hollow tubules. In solid fibres the light is guided within the glass core. If this core is simply removed, then light launched into the fibre would not totally internally reflect and any light entering would reflect out through the walls. In hollow core fibres, the position and size of the surrounding microstructure provides conditions whereby the light is optically nudged by these thin membranes (as determined by a large number of variables including thickness, geometry and refractive index of the glass tubes) to keep it within the hollow central region. There are two main types of hollow core microstructure that allow light to be guided this way:

The range of hollow core fibre types available: a) Photonic band gap fibre; b) Nested antiresonant nodeless hollow core fibre; c) Anti-resonant core fibre.
move it up and down. During a fibre draw, the fibre preform is lowered into a furnace that heats it to around 1800°C. The first glass strands are manually pulled and attached to a tractor system that applies a constant controllable tension to the glass as it passes through the furnace.

As the fibre is pulled out of the furnace it passes through diameter monitoring equipment to allow feedback and variation of the draw speed, which in turn changes the diameter of the fibre produced. It also often passes through one or more coating dies, which uniformly coat the outside of the fibre with a protective polymer jacket. Finally, the fibre is spooled and ready for use. The intricacies and design of these fibres has only been possible through techniques learned from solid fibre drawing experience and the development of specialist glassware handling and drawing processes and facilities.

**SOLVING CHALLENGES**

There are still several challenges to solve before wide-scale adoption can take place. The challenges include scaling up production of some of the more intricate designs and finding coatings that ensure that the fibres are as robust and flexible as their solid core counterparts. Previous work on coating and protection of solid fibres can help inform and facilitate rapid progress. The intricacies of the core designs are a unique problem to hollow core. Designing the stack layouts and then producing methodologies to achieve such layouts is one of the biggest challenges. However, as with solid core fibres these technical challenges are being solved alongside their commercial uptake.

In the last year, two large-scale initiatives focused on hollow core fibre have been launched: the Engineering and Physical Sciences Research Council awarded the University of Southampton £6.1 million for its AirGuide Photonics project, which works with 32 collaborating companies. Second, Southampton-based spinout company Lumenisity Ltd has recently been formed to help commercialise the technology, with a focus on telecommunications and data communication applications. Hollow core fibres are a technology that is poised to move from the lab into applications across the engineering industry. They are set to help solve some of the challenges and limitations of the current generation of solid silica fibre and expand fibre optics into new and exciting areas. While they are still evolving and developing, they are already showing significant promise. Anyone with an interest in telecommunications, 5G connectivity, high-power laser applications, fibre lasers and sensing should start looking at hollow core fibre as the future.

**BIOGRAPHY**

*Dr Matthew Partridge* is a Senior Research Fellow at the University of Southampton. His work focuses on the application of fibre optics to a wide range of real-world problems, from nuclear waste storage to medical diagnostics. In addition to his research, Matthew runs the popular research-focused blog and web comic ErrantScience.com.