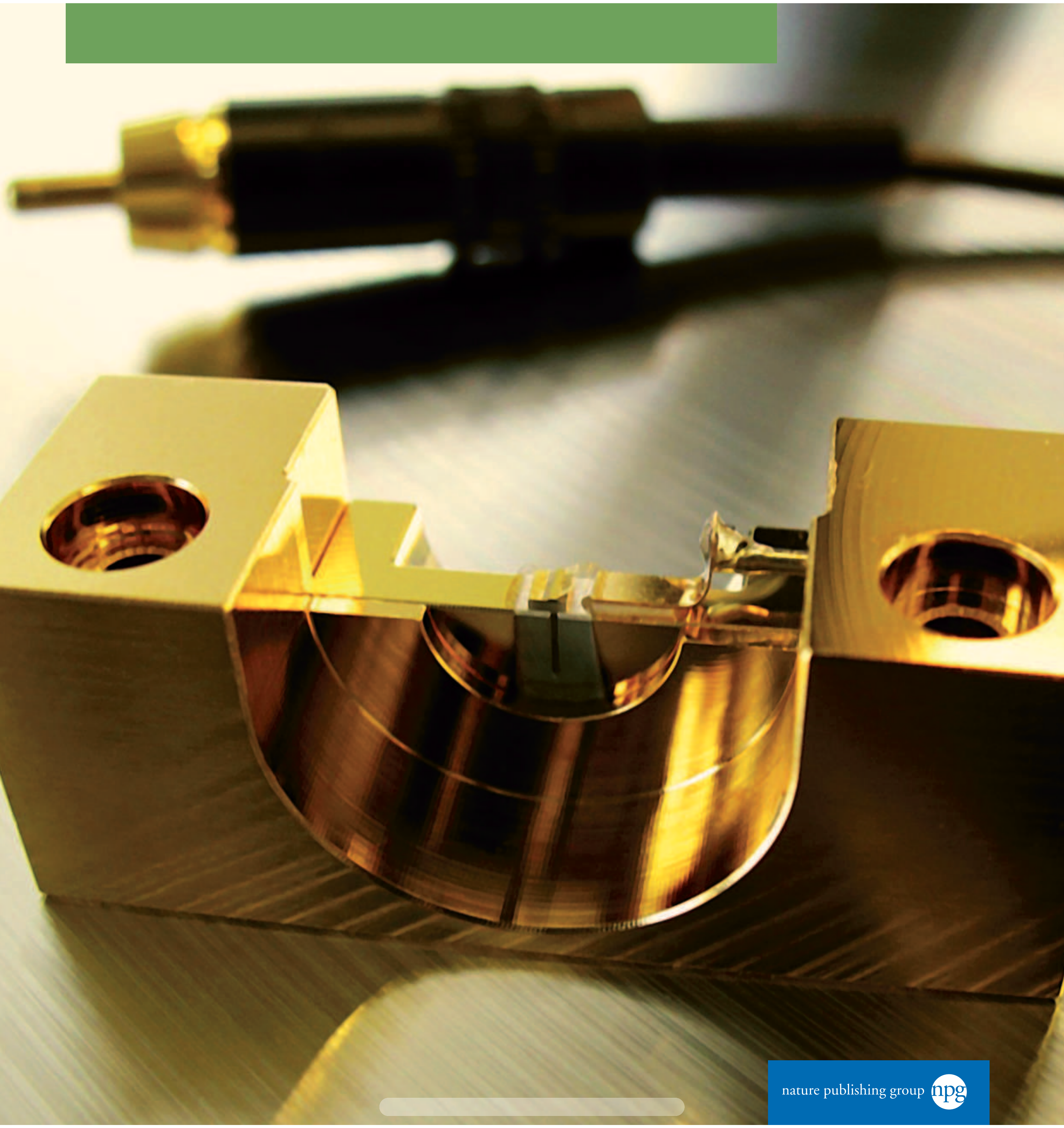
nature photonics

TECHNOLOGY FOCUS



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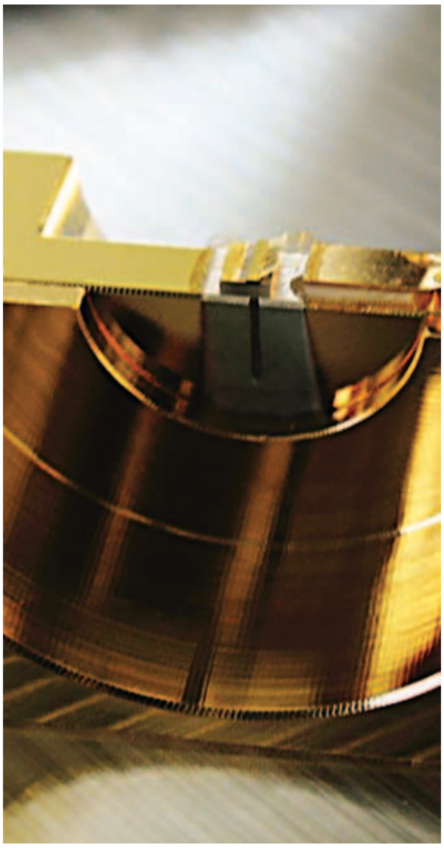

COVER IMAGE

Re-writing the rules

emiconductor science can be confusing. The textbooks we studied at university tell us one thing and the real world often tells us another.

We were told that the emission wavelength of a laser depends on the material system on which it is based. Not so for the quantum-cascade laser (see p32), whose emission wavelength is dependent on its structure and not the material used.

Theory tells us that semiconductor lasers based on quantum dots should have remarkable temperature-insensitivity. But for many years industry was unable to turn this theory into practice. Manufacturing the quantum dots has been a challenge, but finally, 20 years after the prediction was first made, products are coming onto the market (see p30).

In the area of VCSELs, many did not believe that long-wavelength versions could find applications in the telecoms market; with today's shift in demand away from long-haul towards local area networks, however, these devices look set to take off (see p27).

Another area that looks promising for the next few years is tapered laser diodes. Textbooks tell us that ridge-waveguide-laser diodes give us good beam quality, whereas broad-area diodes give us high power. Now a German start-up company has shown that you can have both at the same time by using a tapered laser diode that provides high beam-quality and high power (p24).

The race for a silicon laser is also a classi example of the textbooks telling us it is no possible and researchers defying the odd Groups all over the world are coming u with ingenious tricks to try and get sil to lase. But Larry Coldren, a professo University of California, Santa Barb the US still feels that a pure silicon highly unlikely to have the power required for practical applicatio But who knows?

CONTENTS

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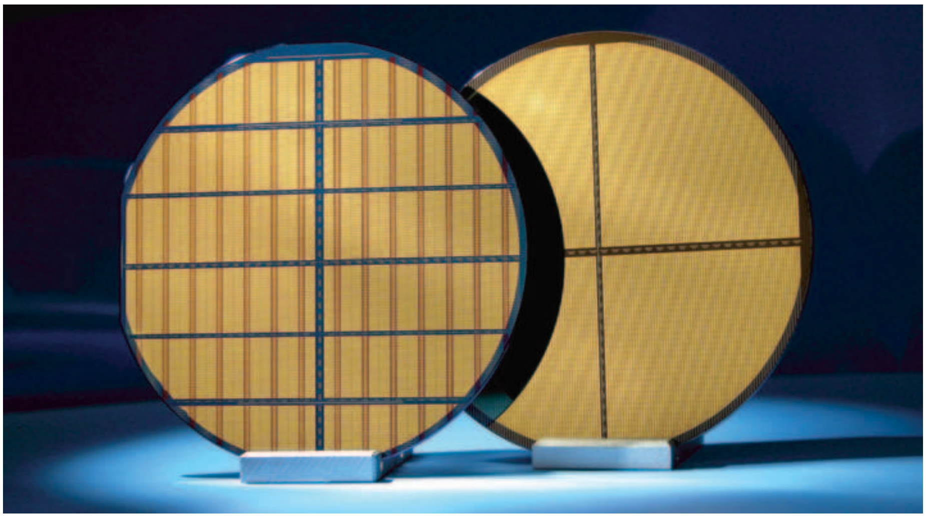
Tapered triumph

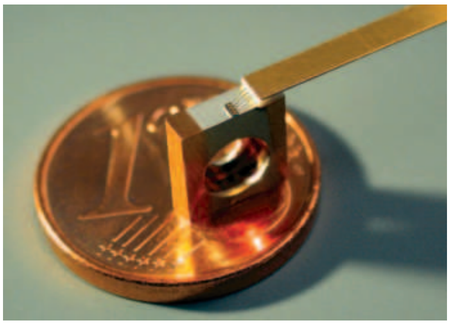
The tapered diode laser seems to have the best of both worlds: it combines the high beam-quality of a ridged waveguide design with the output powers previously only available from broad-area diode lasers. With such attractive properties, it is perhaps surprising that there are so few companies making them.

German company M2K Laser claims it was the first company in the world to commercialize tapered laser diodes successfully, and today it still only has one or two competitors. In other high-tech industries, companies can find themselves in this position through clever intellectual property protection or patenting, but not so for M2K Laser. Its products are based on technology that has been developed as part of German and European research projects and has therefore been published extensively.

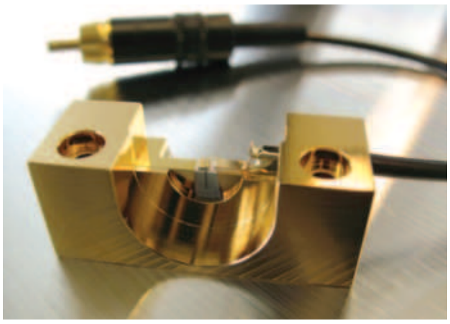
So what makes this company unique? What has enabled it to get a head-start in a market that looks set to take off in the coming years? “Our people,” says managing director and co-founder Márc Kelemen. “Our company spun out of the Fraunhofer Institute for Applied Solid-State Physics (IAF) in 2001 and so we have some very talented technicians, engineers and scientists.”

The company still has very close ties with the institute, which still performs epitaxial growth for M2K’s products. “Through the IAF, we have access to excellent molecular beam epitaxy equipment,” says Kelemen. “This is extremely important for the success of our products.”





It is relationships such as this that have made the company successful. Although only small — it employs 15 people — M2K is able to tap into some important expertise and markets through its connections. For example, it has had a long-standing relationship with German company DILAS Diodenlaser, which it uses for example to commercialize its GaSb-based products relying on DILAS’s experience in packaging and fibre coupling. And in 2007, M2K was bought by DILAS’s mother company Rofin-Sinar. “Not only does this give us access to Rofin-Sinar’s large sales and marketing network, it also gives us a large market within the Rofin-Sinar group,” says Kelemen. “We are the only company within the group that is involved in processing laser diode chips, so we can offer many of Rofin-Sinar’s companie special tailored diode laser solutions previously not available on the market.”



M2K now concentrates on the design the chips and the processing of the wafe leaving the epitaxy and packaging to it partners. Ramping up the processing from development through to produc has been a steep learning curve. “Bei the first company to do something advantages because you are the firs market,” says Kelemen. “But being also means that there is no-one to so we have to sort out our own p

Being the first to do somethin does not seem to scare Kelemen colleagues. A few years ago, in c with the IAF, the company deve mid-infrared diode lasers based antimonide (GaSb) and it is sti company in the world making lasers based on this material s an emission wavelength betw 2.5 µm, GaSb lasers have all t semiconductor lasers but in t regime previously dominated lasers. They have application defence and materials-proce where their wavelength port

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Tapered lasers explained

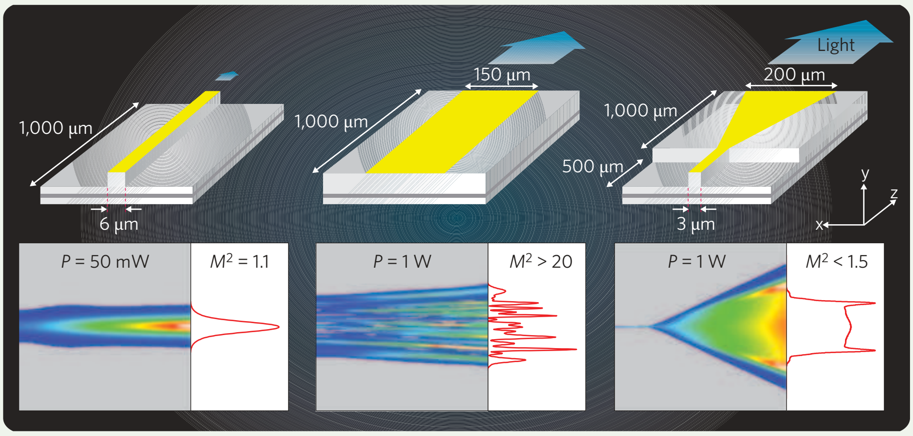
Tapered diode lasers combine a nearly diffraction-limited beam quality with output powers that have previously only been available for diode lasers with broad-area design.

Today, broad-area diode lasers are used to achieve high power outputs. However, standard broad-area waveguide designs are susceptible to modal instabilities, filamentation and catastrophic optical mirror damage failure. This results in poor beam quality and limited brightness. Better beam quality can be realized with ridge lasers that emit a diffraction-limited optical beam, but the downside of this approach is that output powers are relatively low. The reliable output power of these ridge lasers is mainly limited by the onset of facet degradation, which depends on the power density on the facet. Owing to the small stripe width of a few micrometres, the output power is typically limited to several hundred milliwatts.

In contrast, a tapered diode laser (which combines a laterally tapered gain section with a ridge-waveguide) can produce an almost diffraction-limited beam with an output power of up to several watts in continuous wave operation.

The result is a source with a brightness of approximately 10^8 W cm^{-2} sr^{-1} compared with about 10^7 W cm^{-2} sr^{-1} for conventional semiconductor lasers.

An advantage of the tapered approach is that its fabrication is reproducible and low cost. The lasers are based on an InGaAs/AlGaAs layer design grown by molecular beam epitaxy on 3-inch substrates. The ridge and taper sections are processed by using optical lithography and wet chemical etching followed by a lift-off step. After thinning and cleaving, different coatings are deposited by reactive magnetron sputtering. In principle, these devices can function as either an amplifier or a laser depending on the facet coatings. Finally, the devices are mounted p-side down with gold–tin solder. Uniform pumping of the laser medium is achieved by current injection through bond wires.



tunability is particularly useful and sets them apart from solid-state lasers. Kelemen admits these are all niche industries, but, as he points out, "materials processing applications need lots of power, which means orders usually consist of many laser bars".

The main market for tapered lasers is currently the spectroscopy market. However, the company has also seen growth in demand for devices used in frequency doubling. Applications include green and blue laser light for mobile projection displays. Green lasers for this application currently do not exist, so frequency doubling of a near-infrared laser is the only option. "We have seen a renaissance in this area over the last two or three years," says Kelemen. "I was not convinced about the frequency doubling market at first because of the availability of direct blue diodes, but the price of our devices plus a frequency doubling crystal seems to be comparable to the price of a direct emitting diode laser. And, for frequency conversion, tapered lasers are the only devices that have the required output power and beam quality for many display applications."

One of M2K's main future markets for tapered lasers will be the supply of pump lasers. This is where Kelemen believes the tapered laser design will really take off. "In the early years, people buying pump lasers just wanted power, cheap power," he said. "Today many people need power density and this means brightness."

For example, fibre core diameters are decreasing from 200 µm down to 100 µm used today and 50 µm in the future. Typical broad-area semiconductor lasers can only focus down to 100 µm whereas tapered lasers can easily be coupled to substantially smaller core diameters.

"We are now starting to look at transferring our ideas to pump lasers," says Kelemen. "But we realize we need to reduce our costs to compete." The company is convinced that with growing laser bar business, the yield of its tapered laser manufacturing process will rapidly increase and therefore prices will decrease.

Despite having comparable costs to direct emitting diodes, M2K recognizes it still needs to bring down the costs of its products to stay competitive. For example, its GaSb-based products are currently made using 2-inch wafers. An increase to 3-inch wafers would significantly increase yields, but obtaining good-quality 3-inch substrates is challenging. "We are now starting to get 3-inch wafers, but crystal growth is not easy," says Kelemen. "But our products are comparable in price to InP-based devices, even though we use 2-inch wafers."

As well as reducing costs, the company also plans to extend the wavelength range of its mid-infrared lasers. "Our devices can currently go up to 2.5 µm, but for many applications, especially in the medical field, 2.9 µm is an important wavelength because this is where there is the strongest water absorption peak," says Kelemen. Although quantum cascade lasers are available at longer wavelengths, they do not have the power needed when entering a shorter wavelength regime. However, Kelemen believes M2K's broad-area lasers can go up to 2.9 µm while maintaining the required power levels.

Kelemen admits that many of M2K's markets are small, niche markets, but he believes this has advantages, especially in today's financial climate. "The financial crisis has so far not affected us because of the diversity of the defence, medical and scientific fields," says Kelemen.