LASER MICRO MANUFACTURING: PATHS TO PRODUCTION

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Introduction

Micro manufacturing is expanding into an ever-widening number of industries and applications. As it does so, more scrutiny is being applied to its strengths and weaknesses and so it is interesting to note the state of this high-tech landscape.

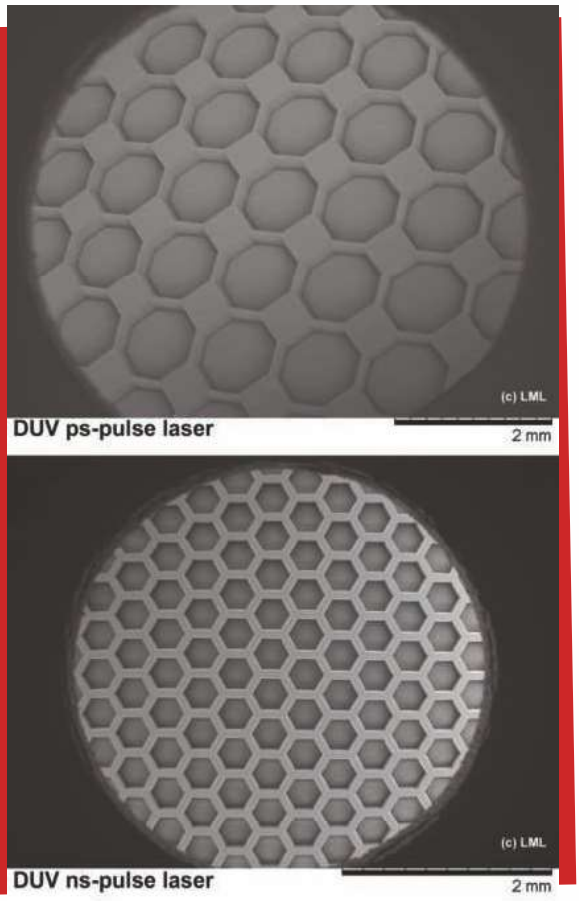
Many technologies can be used in the production of micro parts and these include injection moulding, CNC machining, waterjet cutting, electro-discharge machining, additive manufacturing, chemical etching, electro-forming, diamond turning, hot embossing and laser machining. All of these technologies have been around for decades, in one form or another, but all have recently been developed to extend their capabilities, resolutions and precision into the micro domain.

Laser-based machining techniques, however, have emerged as being unrivalled in terms of being the most versatile, possessing the widest material coverage and offering the highest quality and precision; these are addressed below and the figures throughout show some examples of parts which can only be made directly using laser-based processing.

Macro and Micro

The vast majority of laser manufacturing worldwide concerns the cutting, drilling, marking and welding of metals (and, to a lesser degree, for other materials like wood, plastics and textiles). The bulk of this work is done using high-power Nd:YAG lasers in the near infra-red or carbon dioxide lasers in the mid-infra-red (with continuous wave or pulsed laser outputs). For the sake of simplicity all of this work can be referred to as laser 'macro manufacturing' since micron-level precision and resolution are not normally required (or even possible).

There is one key differentiator between macro and micro manufacturing, however: most tasks in macro manufacturing are deemed mature so that established, universally-used laser processes exist. This means that the same task can be carried out anywhere in the world by different people and identical results will be produced as long as the right 'recipe' is used. Since these recipes (for laser type,



<< Figure 1: Shapes milled into polycarbonate using DUV ps laser (top) and DUV ns laser (bottom). >>

laser power, cutting speed, gas assist parameters etc.) are now well established, laser equipment can be produced which has the processes for various tasks built into it and hence what can be achieved becomes an issue of equipment supply and training, not one of process development and operator skill.

In contrast, universal process recipes in micro manufacturing essentially do not exist and each manufacturer or supplier approaches each task in their own way, sometimes quite radically differently.

There are a number of factors at play here but the main one is that there are so many more choices of laser in micro manufacturing than there are in macro manufacturing. Whereas macro manufacturing is reliant on high-power infra-red lasers, micro manufacturing encompasses lasers with wavelengths from the UV through to the near IR, pulse durations ranging from femtoseconds through to microseconds and powers ranging from mW through to hundreds of watts. With such a wealth of laser options, it is not surprising that the same task can be done with essentially-identical results using different laser processes. This is illustrated in figure 1 showing the machining of polycarbonate with a DUV picosecond solid-state laser (top) and a DUV nanosecond excimer laser (bottom). The two images in figure 1 display identical quality and precision despite the fact that they were machined using completely different laser systems and processes; it is this aspect of micro manufacturing that is both a major positive (i.e. great versatility) yet can also lead to confusion (i.e. which process should be used, which is 'best'?).

Finding the Right Solution

Products incorporating micro parts or miniature components usually require highly specialist processes to produce them and these may not be easily available, if they exist at all. Often the added value in a new micro product (both commercially and technically) is largely due to the fact that similar ones do not exist on the market but the counter-point to this market opportunity is the fact that new production developments may well be required and this poses the problem of finding the right manufacturing solution.

By their very nature micro technologies are at the cutting edge of science and they frequently integrate new materials and new processes in novel ways. What is often surprising, however, is the sheer pace of new developments and how quickly they can end up in new products. This is, in large part, due to how effective and streamlined the route-to-market has become and the flexible ways in which companies now access the latest techniques. Different types of bodies can offer varying solutions:

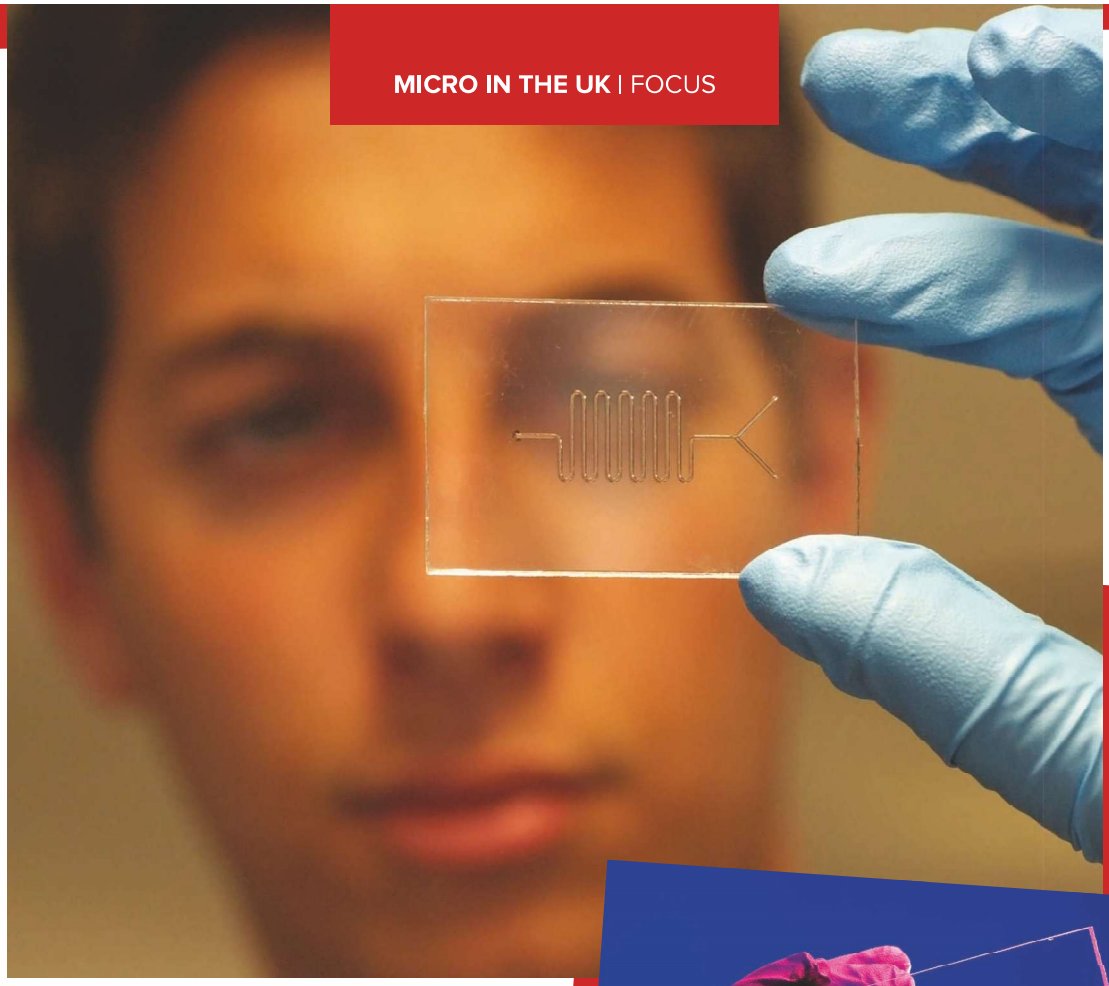
Universities: Academia has always led the way in exploring new ideas and extending the boundaries of what is possible and the main role of universities remains that of providing the ground-breaking research. Increasingly, though, universities have also been more active in exploiting their new discoveries, either by forming businesses themselves or by partnering/licensing with outside companies. Universities may not always be the most efficient vehicle to take ideas quickly to market and often the approach which works best is to allow the research to be commercialised outside of the academic sphere.

Research Centres/Institutes: Often allied to (or residing in) universities, research institutes extend the academic work with more focus on applied/commercial solutions. These centres undertake direct commercial work into how to transfer research ideas into production-worthy processes and they can also be part of a larger network of technology providers, pooling wider resources and undertaking collaborative projects (e.g. as part of regional, national or EU-funded programmes).

Development Houses: These commercial entities are contracted by companies to come up with full industrial solutions for their product ideas. These development houses (sometimes known as Technical Consultancies) generally have some manufacturing capabilities in-house but mainly sub-contract other methods which are required. This kind of operation is being increasingly used by many large companies to out-source their development operations and to 'buy-in' fully-formed product solutions.

Laser Companies: All laser companies have in-house applications labs which are used to demonstrate the capabilities of their lasers and to perform demonstration work for customers to prove that particular lasers can be used for the desired tasks. Some laser companies also now offer fully-integrated laser workstations which can be used in factories for industrial production work.

OEMs: As suppliers of laser-based manufacturing tools, OEMs usually bring together a wealth of external and proprietary know-how to provide bespoke solutions to a company's industrial requirements. OEMs end up working with laser companies, and sometimes with universities or institutes, to develop the most suitable industrial solution. Increasingly, OEMs and laser companies are tending to compete since they can each supply similar production tools.



<< Figure 2: Prototype micro fluidic chip laser-machined in polymer. >>

<< Figure 3: Polymer plate with laser-machined micro prisms for photonic applications. >>

Job Shops: For a company to undertake production of parts within their own business not only requires a large capital investment (for the equipment and fitting out suitable laboratory space) but also needs skilled, trained personnel to deliver the right results. This is not simple and is often a commitment which is not economically viable for many reasons; hence it can be very attractive to sub-contract out this production. Job shops are excellent at retaining different kinds of laser processing equipment and their permanent (highly trained and skilled) staff can offer services which a business cannot usually afford to possess itself. Bearing in mind that the customer company does not have to outlay for any of the hardware, training, consumables, personnel costs or overheads, the cost of out-sourcing production can be highly economic and can also provide great business flexibility.

Factories and Job Shops

One of the reasons why macro manufacturing has grown so rapidly and is now so widespread is because it can be implemented reliably with minimal risk. This has led to the situation where, for example, car plants around the world are running laser macro manufacturing processes on a 24/7 basis, often using robotic handling to automate the processing further.

Other industries (such as food packaging, electronics, aerospace) are also using macro manufacturing in factories, churning out millions of macro parts. In these macro sectors, OEMs and laser companies can supply laser macro manufacturing tools allowing the production solution to be implemented by the customer on a large-scale basis in a cost-effective and reliable way. However, the same OEMs and laser companies also supply tools to macro job shops and so a lot of options exist for doing the same work, either in-house or by a job shop. The message is clear — whether you wish to buy the equipment to do the macro manufacturing job yourself or sub-contract out the task — the results will be the same. This market, therefore, can appear highly homogeneous since all suppliers can offer the same results (but they have to work hard to seem distinctive or to add value).

Since micro manufacturing cannot (as yet) offer recipe-based tools for most tasks, there are far fewer options for companies to buy standard production equipment — virtually every tool has to be, to some degree, a bespoke item with specially-developed processes. A few exceptions obviously exist to this rule and some processes are already in production with an accepted

<< Figure 4: Laser micro machined curved mould tool inserts. >>

methodology, for example the drilling of diesel fuel injectors for cars, annealing of TFT panels for displays and the production of Kapton plates for ink-jet printers. There are thousands of laser micro manufacturing tools around the world performing production tasks but the point is that they have been specifically set up for only doing those tasks — were a slightly different job to appear (or maybe the material or its thickness were to be changed) then a completely new process set-up would have to be found and this may not be simple.

This diversity of options which exists in micro manufacturing does mean that the market is far more fragmented than in the macro one and it also means that fewer companies currently find it easy to bring micro manufacturing processes in-house. Hence the role of development houses and job shops, in particular, has become more central in developing industrial laser processes since they have the required skills and equipment to do so effectively. Job shops not only develop processes but also undertake high volume production of parts — this is good for getting micro products to market but it does not help in standardising the processes any further (since each job shop will undertake the work differently, as already described).

Benefiting from micro manufacturing

The current status of laser micro manufacturing is rather complex and can be difficult to convey to those not familiar with its strengths and downsides. On one side it is clear that amazing results can be achieved with laser processing yet on the other hand the problem is that finding the right solution — how to achieve those amazing results — is not trivial.

The big upside of laser processing is that once there is an established process it can be made extremely robust and reliable, ideal for routine production, but currently there are relatively few companies that possess the necessary process development expertise to generate production solutions; certainly it is not a case that anyone can buy a laser and expect to get the best results with ease. A lot of the required expertise lies within laser companies, OEMs and job shops but it can be quite a challenge to explain the complexities of micro manufacturing to potential users so that they can understand the benefits and commit to these new technologies.

One of the problems that the laser micro manufacturing industry faces is how to extend its uptake into new markets and to new customers. One of the main drawbacks of laser micro manufacturing, however, is that the great versatility of processing can make it difficult to engage with new users – it can be quite confusing for a customer to hear that different companies may solve their problems in distinctly different ways; novice users can find this dazzling diversity somewhat off-putting.

Wider promotion of the benefits of laser micro manufacturing is surely going to help potential users in understanding how they can gain a competitive advantage by adopting new laser processes. In addition, some consolidation of processes will no doubt occur over time so that it becomes easier to implement micro processes more easily in industry, just as it has done in the macro sector. Until such time, the slightly unusual situation is likely to continue: powerful techniques for precision fabrication exist but while there are lots of options, relatively few companies can demonstrate them and those that can do so usually do it in their own way.

It is not often the case that less choice is seen as an advantage but in the case of the plethora of micro manufacturing processes, this might be something that can help the technology take a firmer foothold and gain a better profile in industry. The case for some process standardisation may be worth making, assuming that the laser and processing industries can agree a practical way forward.

Future production

Laser micro manufacturing techniques can produce virtually limitless features with superb precision and excellent quality in all materials. Micro products are available all across society, in every home, in every office. This situation is only likely to increase as new products come on the market or existing ones are miniaturised. In the end a combination of technology and economics will dictate the growth of micro production and how the manufacturing industry meets the demands for production. However, one thing is clear – micro manufacturing is revolutionising production worldwide and micro processes are set to grow bigger.

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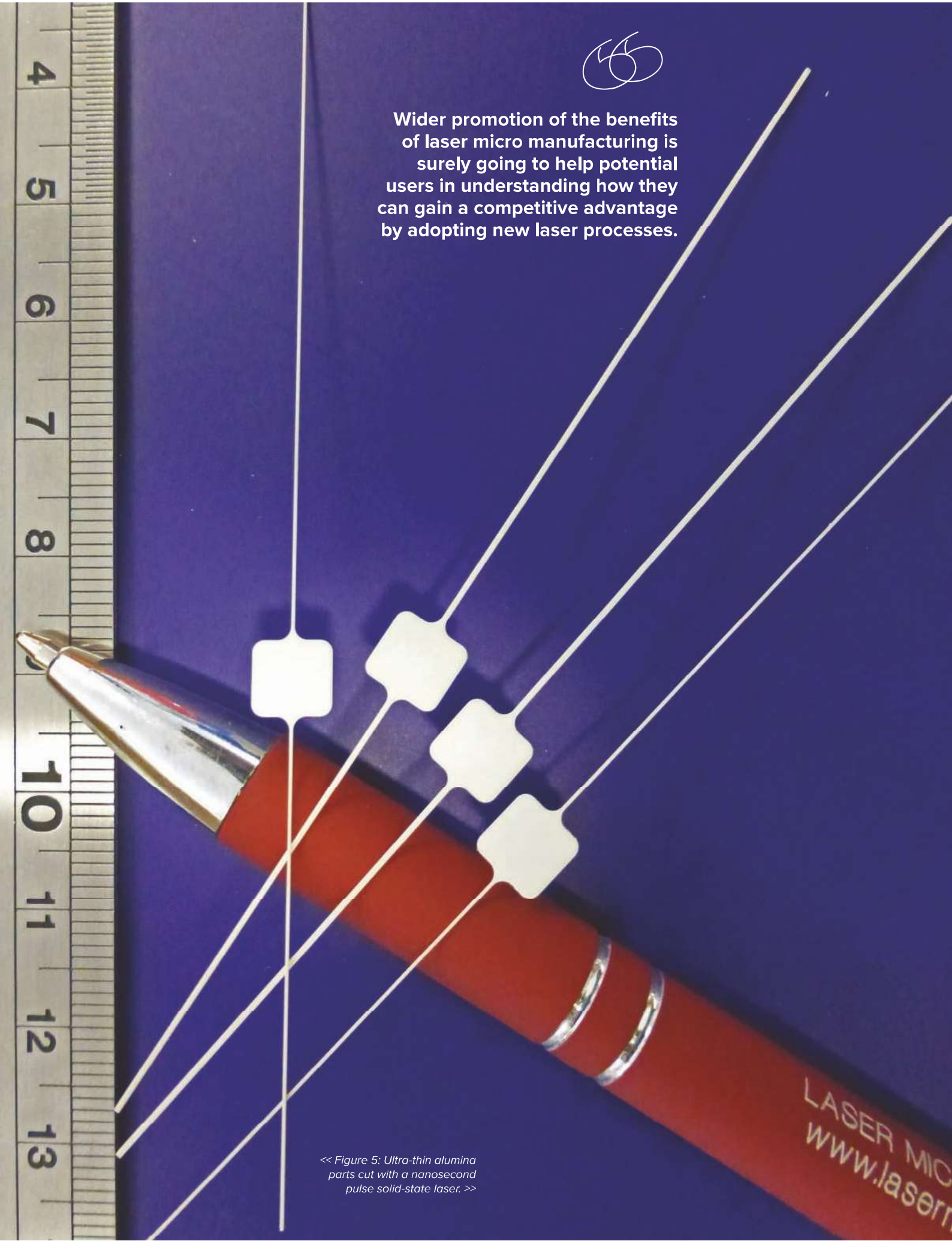

<< Figure 5: Ultra-thin alumina parts cut with a nanosecond pulse solid-state laser. >>