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Micro-Machining

The right technology, for manufacturing balloons and catheters, can result in a range of design elements.

Drug eluting balloon (DEB) and drug delivery catheter (DDC) based treatments are increasingly being offered and used for the treatment of coronary, peripheral, neurovascular, and ENT applications. European markets have already seen a larger acceptance of these therapy choices ahead of the U.S. markets. However, large, randomized studies are underway in various stages of data collection to clearly quantify the advantages of balloon catheters over drug eluting stents (DES), long standing procedures like percutaneous transluminal angioplasty (PTA), surgical interventions (e.g., atherectomy or grafts), and drug therapy-like tissue plasminogen activator (tPA). The various clinical trials have produced data that indicate the balloon design (specifically its ability to deliver drugs at both the correct location and improve drug uptake), and the procedural techniques used, are among the major factors determining the success or failure of a therapy. Design concepts include hole/opening size and density, complex geometry of the balloon and catheter with multiple lumens and surface structure modifications while maintaining a vigil on cost control. Advances in laser micro-machining technology, which include the capability of compensation for material and geometry variations and feature placement, offer device engineers an expanded toolbox to create better DEB/DDC devices, as well as keeping costs under control.

In its broadest sense, laser micro-machining applies to a specific window of all laser manufacturing where the feature sizes range between 1µm and 1mm. The features can be measured as size, depth, or density. Running a large gamut of wavelengths, lasers offer material removal methods based on a thermal process (400nm to 10,600nm visible & IR lasers like Nd:YAG or CO_2) or a photochemical ablation process (<400nm UV lasers like excimer or higher harmonics of solid-state lasers). In addition, the latest buzz in the industry is from ultrafast lasers – material removal is determined less by the wavelength and more by the extremely high energy densities (temporal and spatial) delivered in a Pico- or Femtosecond timeframe. A typical laser micromachining system has four components – laser source, optical system for laser beam delivery, mechanical system for device handling and manipulation, and camera vision and software controllers to integrate all the components.

For thin film metals and polymer devices, UV laser technology enables

Ideal Scenario – Uniform Wall Thickness

the manufacturing of devices according to a highly desired combination of smallest feature sizes and highest quality. This is possible due to non-thermal material removal and the inherent high resolution of short wavelength light.

To offer a comprehensive and successful laser manufacturing solution, the provider must answer three fundamental questions:

- Based on material, what type of laser and starting parameters should be used?
- Based on feature spec and cost, what is the optical design?
- Based on feature location and device geometry, what mechanical system should be used?

Catheter Micro-Machining

Catheters are the primary mode of delivering devices, drugs, and surgical tools through ports to the human body. Coronary, peripheral, neurological, renal, and gastrointestinal diseases requiring intervention use catheters for affecting a therapeutic method.

The peripheral arterial disease (PAD) market is a rapidly growing market for development and treatment. With a gradual reduction in profits from the established interventional cardiology arena, device manufacturers are encouraging a larger investment in PAD. Peripheral disease treatments include drugs, stents, atherectomy, graft, balloons, and a combination of these therapies. To that end, catheters are used as a delivery vehicle, and current designs are improving drug delivery and arterial wall uptake, mechanical plaque breakdown and subsequent removal.

The neurovascular market is seeing a significant growth from therapies that target aneurysms, tumors, ischemic stroke, and neural vascular malformations. Micro-catheters are used in conjunction with stent-type retrieval systems to treat and remove emboli. Coils are inserted in skived ports in catheter lumens to deliver targeted therapy for preventing rupture of aneurysms and/or neurostimulation.

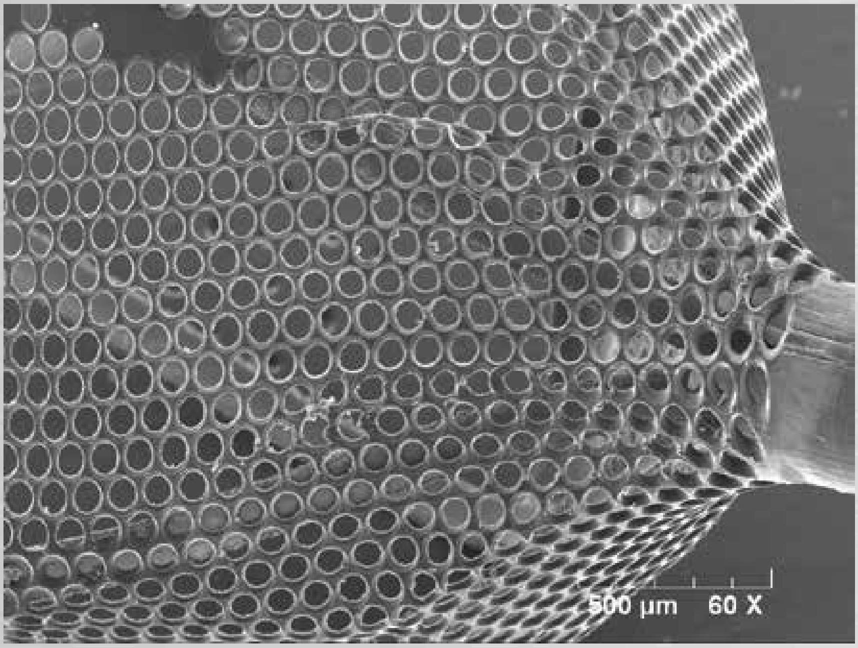
Laser micro-machining of catheters offers the ability to include design elements for improvement of drug deliver, catheter size, position and design of ports, and selective removal of coatings on braided catheters which improves flexibility.

DDC Example

Let us look at an example of drilling holes and skives at specified locations on a polymer multi-lumen DDC. Common materials chosen for catheters include Pebax, nylons, and fluoropolymers (e.g., FEP and polyimide). Various design and material challenges are presented and solved with new advancements in laser micro-machining.

- **Design Criteria: Uniform precise holes less, than 100μm in diameter, and skives with no bulk material damage.**
  - o Manufacturing Solution: UV Lasers
    - ▪ UV laser wavelength offers high resolution and photochemical ablation process that produces holes and skives with no manufacturing artifacts and with tight tolerances. Solid-state lasers are available at 355nm and 266nm wavelengths; excimer lasers operate at 308nm, 248nm, and 193nm. A rule of thumb is that the shorter the wavelength, the higher the resolution and quality of ablated features.
- **Design Criteria: Compensate for variable wall thickness.**
  - o Manufacturing Solution: Excimer Laser Pulse Control
    - ▪ Capable of removing material at 100nm to 300nm per pulse, excimer lasers can offset a significant percentage of catheter extrusions with variable wall thickness.
    - ▪ Based on the process, the laser beam can achieve a constant pulse dose based on the thickest wall dimension.
    - ▪ Compensate pulses per location using end point detection techniques.
- **Design Criteria: Close packed 10μm to 30μm holes in lumen for more uniform delivery of thrombolytic agents and surface modification.**
  - o Manufacturing Solution: Mask Projection UV Excimer Machining
    - ▪ Mask projection refers to the use of a large, higher-order beam to illuminate a mask with a desired hole pattern, then producing a de-magnified image on the workpiece. The advantage over small beam direct-write approach is essentially an economy of scale and potentially faster and better uniformity of the drilled holes.
    - ▪ A single array of holes can have different diameters and shapes.
    - ▪ Excimer lasers remove material at rates of 100nm/pulse to 300nm/pulse.

Multi-Hole Drilling in 3D Shape



• **Design Criteria: Partial removal of coating to increase flexibility.**

o Manufacturing Solution: Homogenized Excimer Beam

▪ Optical design delivers a modified beam with a uniform energy density in a shape matching the desired feature shape.

▪ Beams as long as 3" can improve the throughput and provide uniform circumferential stripping of coatings – atherectomy devices requiring selective removal of coatings are beneficiaries of this method.

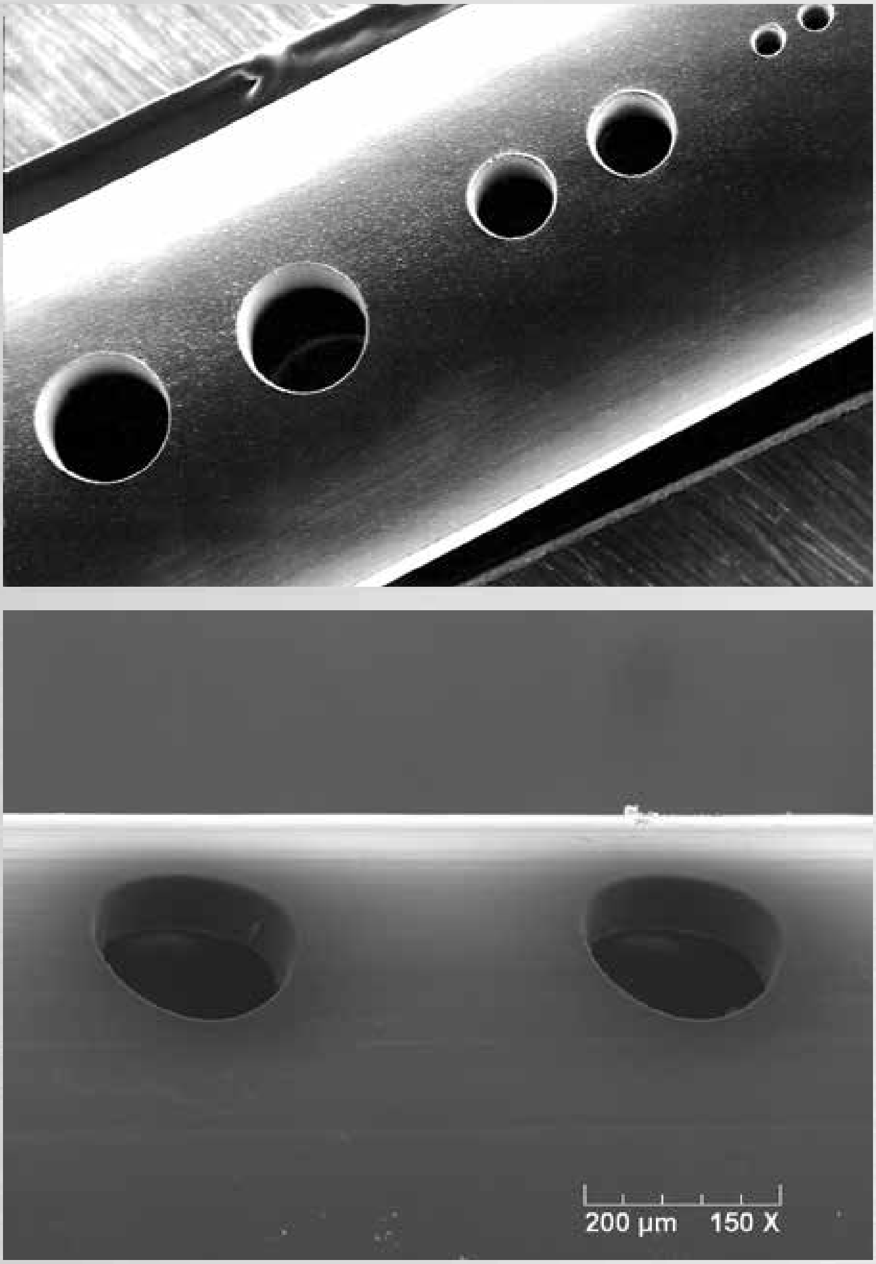
• **Design Criteria: Multi-lumen catheter design to deliver multiple devices and drug formulations at the site of treatment.**

o Manufacturing Solutions: Vision Alignment; Mandrel Use; Automated Handling

▪ Vision System: The combination of multi-lumen construction and reduced stiffness across extended lengths result in lumen twist along the length of the catheter resulting in a manufacturing problem when holes or skives need to be placed along the entire length of the catheter.

▪ Mandrel Use: Catheter designs involving lumen sizes smaller than the beam depth of focus require mandrels to prevent damage to the back wall or septum.

▪ Automated Handling: Handling systems play an important role in presenting the catheter at the site of machining; for peripheral therapy DDC, motion stage design involves choosing a combination of long travel stages, vertical compensation, and direct drive rotary stages for precise positioning. Automation systems provide for pick and place, highly accurate indexing, and the ability of batch processing.



Catheter Showing Multiple Precise Holes

Drug Eluting Balloons

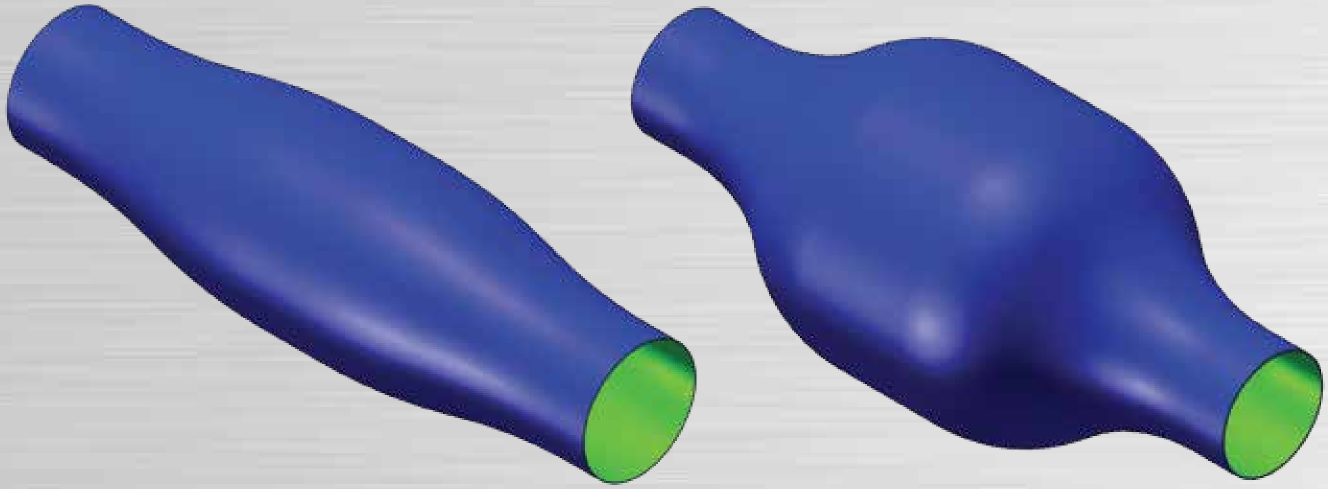
Drug-eluting balloons offer a more challenging issue – from reservoirs for drugs, to delivering electrical stimulation via embedded electrodes, balloons cover a wide range of applications. In addition, balloon geometry is inherently 3D and manufacturing methods have to be able to cover the entire universe of designs.

Micro-Pore Balloons: Used as a drug reservoir with targeted site delivery, micropore balloons have a very high density of holes (typically 50µm or smaller in diameter) placed within one to two diameters of each other. The design criterion requires therapeutic agent to be delivered in a highly controlled and uniform fashion to improve uptake and to minimize vascular wall damage due to the pressurized flow.

Weeping Balloons and Drug Eluting Balloons: These balloons have proprietary coating technologies for the various therapeutic drugs. Intended to improve coating efficacy and/or surface contact, modification of the balloon surface can create channels for drug or fluid flow, or provide a pathway for electrodes to be in contact with the aneurysm (or lesion).

• **Design Criteria: High Density Hole Pattern on Cylindrical Angioplasty Balloon Body**

o Manufacturing Solutions: UV Excimer Laser 193nm with Mask Projection



(LEFT) Small diameter change may allow for 2D approximation for hole drilling.
(RIGHT) Large diameter change requiring 9-axes machining to ensure uniform hole quality.

▪ UV excimer lasers at 193nm wavelength with a mask projection technique can rapidly drill the large volume of dense holes with tight tolerances. Typically, for hole sizes between 10μm and 50μm, tolerances range from 1μm to 10μm. Laser-material interactions (material coupling well with the laser light) and balloon positioning control determines the actual tolerance. Hole sizes down to 1μm are possible in thin walled balloons with active Z-axis (vertical) compensation.

• Design Criteria: Surface Modification or Holes Drilled on Neck and Body of Balloon

o Manufacturing Solution: Mask Motion; Part Motion; Part Mapping

▪ Balloon Mapping. Laser micro-machining requires the part surface to stay at a constant distance from the laser beam and the ablation area to be normal to the beamensuring:

▪ All holes are of the correct size and taper characteristics

▪ All holes have the same shape

o Mask Design/Motion: Use a hole pattern based on balloon geometry and then program the motion of the mask to match the part rotation.

o Laser Control: Program the laser pulse-firing rate and the energy density, if necessary, to ensure that all locations receive the same amount of energy and pulse dosage.

Using vision systems, the balloon surface geometry is mapped to determine the shape and any large changes in circumferential or longitudinal distance from the laser beam, allowing the engineer to program the motion controllers to compensate for shape changes.

• Design Criteria: Non Planar, Conical or Other Complex Shape for Balloon Geometry

o Manufacturing Solution: Nine-Axes Micro-Machining Technology

▪ For laser micro-machining, all surface must be normal to the laser beam when being ablated. To achieve this, a combination of balloon mapping, mask motion, and part motion control is used.

The net effect of the above is a rapid drilling protocol, achieving remarkable uniformity of drilled holes on both planar and non-planar surfaces with all holes meeting the required tolerances and shape.

Various balloon and catheter methodologies are in development, designed to address disease states. For a medical device design engineer, it is important to use clinical and point-of-use data to improve current device designs for effectiveness while simultaneously making the new device cost-beneficial to the patient and the health care system. Laser micro-machining has helped enable this by utilizing advancements in hardware, op tical, vision, and mechanical systems to become a very attractive option as a manufacturing method.

As medical device sizes shrink and their geometries become exotic, the laser micro-machining toolkit continues to evolve and remove obstacles in the path of their manufacturability. **tmd**

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