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LASER MICRO-PERFORATION AND FIELDS OF APPLICATION

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Abstract. Replacing of conventional technology for producing microfilters with a laser technology is presented in the paper. Two approaches for laser drilling through melting and sublimation are discussed. The paper describes possibilities of laser technology in obtaining filters and sieves with different diameters of the holes in the microwave range as well as high homogenity of structures. Detailed analysis of photo-etching as an alternative to laser drilling of microfilters with a certain geometry has been carried out. Advantages and disadvantages of the most common technologies are shown, too.
Keywords: laser; microsieves; microfilter; photo etching; laser drilling

Introduction

Stringent regulatory requirements related to sterilizsation often have to comply with the needs of biotechnologies and food industry. Filter materials such as polypropylene (PP) and polystyrol (PS) are not suitable because at temperatures above 100^0C they have structural changes and there are softening effects on the geometry of holes. Inability to clean such filters by mechanical methods (brushes) or ultrasound is another problem that occurs after damage surface. Polymers are generally resistant to acids and hydroxides. However, prepared seal filters of such materials are destroyed or decomposed by chemical attack. Filters made of ceramic material are resistant to both thermal and chemical effects. The problem is the thickness of the material, namely the thickness-to-hole ratio (100 : 1), which leads to a rapid clogging of the channel through which the fluid is filtered. Another problem of ceramics is the occurrence of micro cracks in the material as a result of temperature gradients. A suitable material that prevents disadvantages listed above is a sheet of chromium nickel steel (Baumeister, 2009; Gehrke, 2007; Jackson & O'Neill, 2003; Baumeister & Dickmann, 2004; Ostendorf et al., 2003). Methods for the production of clean drinking water without any trace of micro-organisms and for environmentally sound treatment of waste water, as well as the production of clean food stuffs, are among the main areas of sustainable technological development of our society. That is why it is necessary to produce a new type of metal filters based on an innovative laser technology.

Comprehensive description

Photo etching technology

Traditional photo etching technology is a very precise, controlled, surface-etching process used to produce sophisticated metal components with very fine detail.[1)] The technology is widespread and successfully applied in preparation of fine micro-filters due to a number of advantages that it offers: unlimited contour complexity; expensive hard tools are not needed; cost-effective design of a particular image design – characterized by the speed and flexibility; rapid application without the material being subjected to stress – thermo-physical and magnetic properties of the basic material remain unaffected; the process lasts for several days, not months; almost any metal can be used in the process; accuracy of up to ± 0.025mm.

The etching process comprises several consecutive steps:[1)] *material selection* – almost all metals used in photo etching; *material cleaning* – selected material is chemically cleaned and degreased to remove debris, waxes and rolling oils on its surface; *lamination* – a photo-sensitive resistant material is applied to the sheet using automated cut sheet lamination; *image printing* – a laser direct imaging (LDI) technology can be used; more accurate technology than conventional photo-tooling; the component design is transferred to the photo-resist by exposing the sheet to the ultraviolet (UV) light; *developing* – the unexposed resist is removed to expose the raw material. The remaining photo-resist, which has been hardened by the UV light, will protect the component during etching; *etching* – etching substance is sprayed onto the developed sheet. The time of etching is determined by a qualified etching specialist depending on the specific parameters (type of material, thickness, geometry, etc.); *stripping* – the remaining photosensitive material is removed from the metal surface to show the etch image; *performing visual and measurement checks* – the component is inspected visually and measured if necessary; *finishing* – finally there are 3D, polished, bonded and plated components.

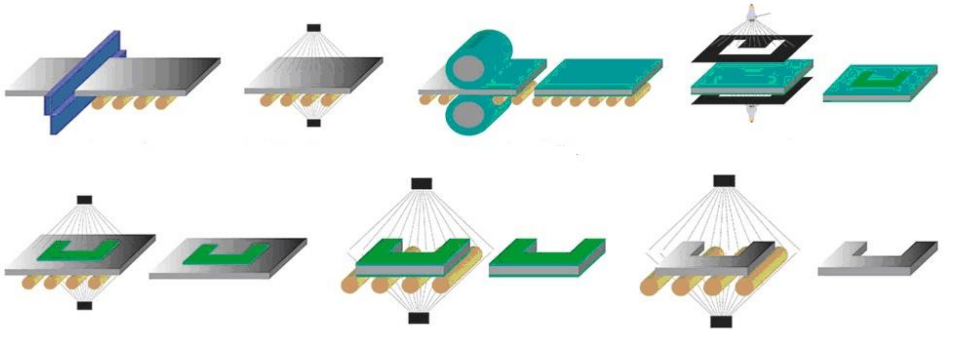


Figure 1. Successive stages of the photo etching process[1)]

Laser drilling of holes

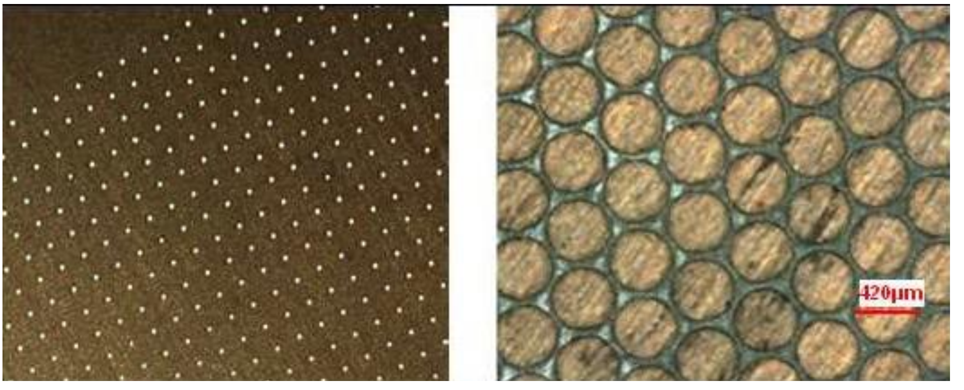
According to the standards DIN 8580 and 8590 regarding laser drilling, it means "laser removal of material as a result of thermal impact in the processing area". The advantages of laser drilling are the high degree of flexibility and the ability to automate the process. Unlike conventional hole drilling methods, the laser is non-contacting (there is no pressure on the material), there is no wear of the tool, and there is no danger of breaking the cutting tool when processing superheated materials. Different materials such as: metals, ceramics, semiconductors and plastics, can be successfully drilled[2)] (Dausinger, 2001; Scanlab AG, 2015).

Single laser impulse drilling is applied when multiple micro-openings on a small area have to be made, for example, in the manufacture of filters and screens. During the process, holes with a size of 10-250 μm are made (Jandeleit, 1997; Kononenko et al., 2002).

Drilling a thicker sheet material (2 mm) allows making holes with a diameter larger than 250 μm. Drilling more than 100 holes per second is possible when using a special scanning optics, i.e. „flying optics", that moves the beam across the surface of the material (Baumeister et al., 2007).

In recent years, companies like "Pulsar Photonics GmbH" have achieved good practical results: drilling micro-holes with a diameter of 20 μm; high ratio (> 10: 1); high process reproducibility within narrow tolerances of <5 μm; different geometry of holes (square, elliptical, etc.); high speed to the kHz range.

The range of application possibilities of this method is extremely wide: ventilation holes, cooling openings, contact holes and filters.



a b

Figure 2. Results from laser drilling of micro-holes:
a) on metal foil;
b) a special structure with high fluid permeability[3)]

Physical bases of laser processing for drilling holes

Processes that occur during laser drilling of holes can be illustrated by two simplified physical models: (i) *Starting phase* from the moment when laser radiation falls onto the material to reach the surface evaporation temperature; (ii) *Removing the substance* from the processing area.

For the start-up phase as in all laser interaction processes, requirements apply to: (a) *Absorption* of falling electromagnetic energy by the material; (b) *Thermal conductivity* of the material and energy transfer into its depth.

In the initial phase, the material is heated to melting temperature. Duration of this phase, i.e. time when laser radiation is falling onto the surface to start the process of the withdrawal of the substance, depends essentially on two factors: effect duration ($t > t_v$) and intensity of laser radiation ($I_0 > I_v$). For surface temperature the following equation applies:

$$T\,(z = 0,t)\ \alpha\ A\ I_0 \sqrt{t} \tag{1}$$

Laser drilling of holes through melting

Removal of the substance is explained by the model of evaporation from a deep crater. A melt bath is formed during the start-up phase of the treatment zone. Upon reaching the melting temperature, metal vapours are formed in the crater, which spreads through it at ultrasound speed. A vaporized pillar is formed and it shields the falling radiation from the melt. Under the action of vapour pressure, the melt

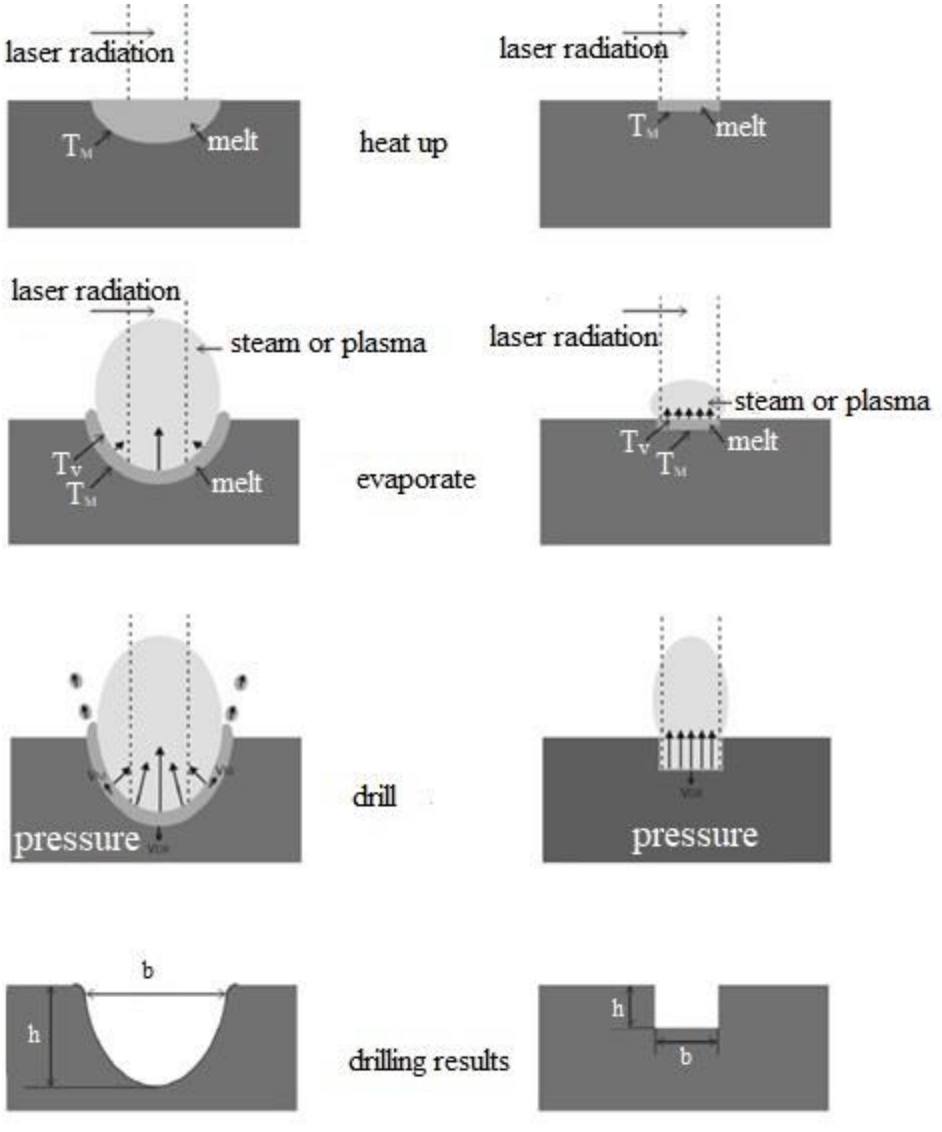


Figure. 3. Schematic representation of the process of laser drilling of holes (left by melting) (to the right by sublimation) (Poprawe, 2004)

is squeezed from the crater's bottom, sliding along the walls to the top. During the transport, a portion of the melt may cool down and stay on the walls, which may result in clogging of the neck of the shaped flask. Criteria related to the drilling quality of holes are the following: the geometry of holes; deposits on the walls of the opening; deposits on the surface around the hole; formation of dross from the outlet side.

Sublimation laser drilling of holes

In laser sublimation drilling of holes the material is removed in the gas phase. The intensity with which this technology is being used is significantly higher than that of the laser melting treatment. The energy required to remove the same amount of substance from a given material *dM* in the gas phase by evaporation is about one order greater than in the melting process.

As a result of the high intensity of sublimation process, evaporation temperature is reached for a very short time t_v and the melt volume can almost be ignored. Screening of the processing zone from the formed plasma cloud can be avoided by appropriately varying and selecting the processing parameters such as pulse duration τ, pulse energy Ei; pulse frequency f.

Compared with drilling by melting, the crater depth is much smaller related to the same pulse energy (P_L . t_L). As there is no deposition on the surface and it is significantly cleaner, the same applies to the deposition on the hole's walls. Here we can talk about a much better quality of the entire geometry of the opening and the channel. Schematically, both methods are presented in Fig. 3.

Under certain limitations of absorption and some other boundary conditions, the equilibrium for the heat balance in the sublimation process can be presented in the following form:

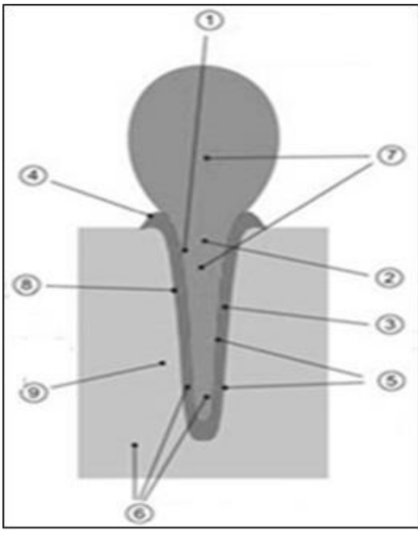
$$E = \rho V (c \Delta T + H_m + H_v), \tag{2}$$

where ρ is density [kg/m^3]; V – volume of the hole [m^3]; c – specific heat capacity [J/kg.K]; ΔT – temperature difference between ambient temperature and evaporation [K]; H_m – melting enthalpy [J/kg]; H_v – enthalpy of evaporation [J/kg].

Along with supplying the necessary laser energy to heat the processing zone to the evaporation temperature, additional energy in the form of the enthalpy of melting H_m and evaporation H_v must be introduced to transform the solid phase material into liquid and, accordingly, the liquid material into gaseous one.

Upon reaching the evaporation temperature, a portion of the laser radiation is absorbed by the gas cloud and plasma is generated for several nanoseconds. For the emergence of this phenomenon it is necessary to reach a critical intensity I_c. The plasma cloud expands to the surface of the material by shielding the falling laser radiation.

In application of the laser drilling technology, a number of physical processes have to be taken into account in a very short time interval (Fig. 4): absorption, reflection, multiple reflection and thermal conductivity; absorption and reflection in plasma and cloud of metal vapor; dynamics of steam cloud, plasma and melt movement; discharging steam, plasma and melt from the crater; cooling the melt and deposition both on the surface and on the walls of the channel.



(1) absorption into plasma and multiple reflection of radiation in the channel; (2) transport of steam and plasma through the crater; (3) movement of the melt on the walls of the channel; (4) depositing and smoothing the melt around the neck of the crater; (5) movement of the phase fronts (melt, money, reconditioning processes); (6) thermal conductivity and thermal fronts; (7) Dynamics of gases passing through high pressure through the neck; (8) cooling and depositing on the walls of the channel; (9) thematic stresses and deformations.

Figure. 4. Schematic representation of the process of laser drilling of holes and the place of the individual physical sub-processes in its realization (Poprawe, 2004)

This complexity and interrelations of the processes makes it extremely complicated and difficult to perform physical and mathematical modeling. Therefore, it is always necessary to carry out preliminary experiments and analysis in order to optimizse the technology for each specific material, taking into account its specific characteristics and geometry.

Alternatives to laser method are the following (Rohde, 1999), (Langmack, 2010), (Kauf, 2001): (i) Drilling of holes using an electron beam: this method mainly treats metals, achieving diameters of holes between 0.1 – 1 mm at a ratio of 10:1 and performance of <1000 holes per second. There is a special requirement for the process, namely to conduct it in a vacuum to avoid electrocution with atomic gas in the working chamber; (ii) Spark erosion method for drilling holes, i.e. removing material from the surface as a result of spark discharge. The method is only suitable for metal specimens. Diameter of holes is < 0.2 mm and the processing speed is small; (iii) .Electrochemical drilling of holes, i.e. removal of anode material in a liquid electrolyte environment. The process is only feasible for metal specimens. The diameter of holes is in the range of 150 – 500mm, the ratio is 200:1, complex geometry of the holes is possible, the surface around the area is of very good quality and there are no stresses in the material. As a disadvantage, low processing speed can be indicated; (iv) Mechanical drilling with borer: it is possible to process almost all materials with industrial application. Minimum diameter is about 30 μm, depending on the type and characteristics of the material, such as the ratio of 20:1. Besides, borers have a very short lifespan; (v) Drilling of holes using ultrasound is mainly used for fragile materials, such as sapphire, granite and ceramics, with the minimum diameter of about 150 μm at material thicknesses of about 0.1 – 50 mm. Processing speed is small, too.

Conclusion

If future laser methods for microfilters and microsieves are developed and validated on large surfaces and their production becomes significantly cheaper, this will open up new prospects for a number of industrial applications in practice. It will contribute to ecological balance by avoiding current technologies that use chemicals and energy-intensive chemicals (eg. ozone, chlorine, heat in the processes of pasteurisation and sterilizsation).

NOTES

1. https://www.precisionmicro.com/metal-etching/
2. http://www.gsilumonics.com/electronics/expertise_application_notes/apps_pcb_micro_drill.html
3. www.pulsar-photonics.de

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