Excimer lasers - a novel tool for fine and microprocessing of glass materials

Access to applications and material effects which are principally not accessible to the commonly used CO$_2$ and Nd:YAG lasers and exceptional properties make the excimer laser an attractive tool for glass processing. The applications include laser marking, structuring of glass, drilling, microtechniques, and cleaning of surfaces. However, despite the wide gamut of possibilities, use of the excimer laser in the glass industry is still uncommon.

**Introduction**

Over the last 15 years, the laser has evolved to become a key technology because of the quality, flexibility and cost effectiveness that it can provide. There is scarcely another technology which is more suited for material fine and microprocessing. Industrial laser applications include cutting, drilling, welding, soldering, marking, trimming, coating, alloying, annealing, hardening, lithography, etc. Each year thousands of laser systems for material processing are installed worldwide.

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The laser has also found access into the glass industry. Standard laser applications in this field are: cutting quartz tubes; scribing quartz tubes and plates; scribing (drinking) glasses with subsequent thermal blast-off of the upper part; sealing glass casings containing electronic circuits (transponders); marking quartz glasses, bulbs and flasks, dyed or coated drinking glasses, cups, etc.; marking and cutting diamonds, drilling diamonds.

Despite these examples, the number of actual laser applications in the glass industry is limited, and behind each of these applications there are only a few producing systems. The manufacturers of lasers for material processing do not even get 1 per cent of their turnover from the glass industry. The reasons for the minor role of the laser in this industry can be found in the features of CO₂ and Nd:YAG lasers, which are the lasers mainly applied up to now.

I. Laser types for industrial glass processing

For industrial material processing, CO₂, Nd:YAG and excimer lasers are almost exclusively used. The reason is that these lasers provide the highest output powers at the highest reliability and cost effectiveness. The wavelengths of the Nd:YAG and CO₂ laser light are 1.064 nm and 10.600 nm, respectively. Both are light in the infrared. For Nd:YAG laser light, most of the standard glasses have very low absorption, which means the laser light penetrates the glass (nearly) without material effect. As a result, Nd:YAG laser processing of these glasses is not possible.

For CO₂ laser light, the glasses have a very high absorption, but the standard industrial CO₂ laser processes only thermally. That is, the glasses are heated up locally until melting and/or evaporation. Thermal stress occurs in the glass, causing damage to the workpiece from local shell braking up to explosion.

The excimer laser is a novel tool for industrial material processing. Within the last five years this laser has continuously gained importance. Excimer lasers are pulsed gas lasers. According to the laser gas applied (XeF, XeCl, KrF, ArF, F₂), laser radiation is obtained on different wavelengths between 351 and 157 nm (see Table 1). The central features of the excimer laser in comparison to CO₂ and Nd:YAG laser are:
- shorter laser wavelength;
- high pulse peak powers (typically 1 - 50 MW);
- short pulse duration (typically 10 - 50 ns).

These features and the high output powers make excimer lasers the most effective and powerful UV light sources, and not only laser sources available today.

Table 1
Dominant laser types for industrial material processing and maximum laser powers typically applied. (In brackets the excimer laser gases.)

<table>
<thead>
<tr>
<th>Laser type</th>
<th>Wavelength (nm)</th>
<th>Laser power range (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>10.600 - 15.000</td>
<td>-</td>
</tr>
<tr>
<td>Nd:YAG</td>
<td>1.064 - 4.000</td>
<td>-</td>
</tr>
<tr>
<td>351 (XeF)</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>308 (XeCl)</td>
<td>-</td>
<td>200</td>
</tr>
<tr>
<td>excimer</td>
<td>248 (KrF) - 150</td>
<td>-</td>
</tr>
<tr>
<td>193 (ArF)</td>
<td>-</td>
<td>75</td>
</tr>
<tr>
<td>157 (F₂)</td>
<td>-</td>
<td>3</td>
</tr>
</tbody>
</table>

Fig. 1
Schematic set-up of an excimer laser marker
II. Material processing with excimer lasers: features

The unique features of excimer lasers give them access to applications and material effects which are principally not accessible to CO₂ and Nd:YAG lasers.

(a) Due to the shorter wavelength, excimer lasers can generate structures with smaller dimensions and much higher precision than CO₂ or Nd:YAG lasers.

(b) Nearly all materials, glasses included, have very high absorption at least for the shorter excimer laser wavelengths. High absorption means effective coupling of the laser light into the workpiece and therefore effective transformation of laser energy/power into process energy/power. High absorption also means small penetration depth (typically ≤1 µm) into the workpiece. The excimer laser light is completely absorbed in an extremely thin surface layer of the workpiece. This allows highly precise processing of the workpiece (ablation, drilling, marking, etc.).

(c) The energy of the photons in the excimer laser light is high, within the range of molecular binding energies of the materials to be processed. Therefore, excimer lasers can process not only thermally (heating, melting, foaming, evaporating) but also photolytically (chemical surface modification, colour change, material removal, etc.). Photolytical processing means the workpiece stays cold.

The exceptional properties and the resulting material effects of the excimer laser make it a highly interesting instrument for fine and micro processing of glass materials.

III. Applications

A. Laser marking

Excimer laser markers are mask markers. The schematic set-up of a corresponding marking system is indicated in Figure 1. The laser beam is deflected onto the workpiece via mirrors. The laser beam illuminates a mask that contains the entire marking information. The mask is imaged onto the workpiece by a lens. The whole of the information contained in the mask is transferred to the workpiece with a single laser pulse.

Excimer-laser marking characteristics include:

• Marking field size

The size of the marking field is limited by the energy density required for the marking process. Typical marking field sizes are 10 x 20 mm². (Larger marking fields can be realised by scanning the laser beam over the mask or by scanning both mask and workpiece under the laser beam. The movement of the laser beam, respectively of mask and workpiece, and the laser pulse frequency are synchronised.)

• Marking speed

The marking speed is a central feature of excimer laser markers. The whole marking content is transferred onto the workpiece with a single laser pulse. Therefore, the marking speed is only limited by the maximum pulse frequency of the laser. Speed is a central feature of excimer laser markers. The whole marking content is transferred onto the workpiece with a single laser pulse. Therefore, the marking speed is only limited by the maximum pulse frequency of the laser and the transportation speed of the products to be marked. Marking speeds up to 100 marks per second and more are standard for excimer laser marking. Since the laser pulses are short (see Table 1), also fast-moving objects can be marked. Sharpness of the mark is no problem with transportation speeds of up to 100 m/s and more.

• Flexibility

Excimer laser markers are highly flexible due to complete computer control of the machine and the process. For example, all process-relevant parameters such as laser power, pulse frequency, etc. can be adjusted via the controller of the laser.

For mask marking, changing of the marking information means changing the mask. Depending on the requirements, such as flexibility, marking contents, and marking speed, different mask systems are available. Examples are stackable and disk masks. For stackable-mask systems, several masks are
stacked one upon the other, while for disk-mask systems, mask wheels with different complete masks are arranged on a wheel. Swinging of the corresponding mask into the laser beam is accomplished manually or automatically, depending on customer demands.

With the laser controller, external units such as workpiece transportation systems can be computer-controlled through standard output ports. Principally, the laser marker can control a complete production line. On the other hand, standard input ports permit configuration of the laser marker by external devices such as host computers. Complete computer control allows easy integration of excimer laser markers onto (fully automatic) production lines. Excimer laser markers are predestined for Computer Integrated Manufacturing (CIM) and Just-in-time Manufacturing.

**B. Marking eye-glasses**

A standard application for excimer lasers is the marking of eye-glasses (Fig. 2), which is accomplished via minimal material removal of 0.1 \( \mu \)m per laser pulse. The result is a permanent engraving with the manufacturer’s logo that does not disturb the wearer. Some reasons for using the excimer laser in eye-glass marking are:

- high quality and good reproducibility of the process: the marks can be read safely with the first eye-glass as well as with the 10 millionth;
- no (micro) cracks: the rupture strength of the eye-glasses is fully preserved;
- no mechanical contact of the tool (the laser beam) with the eye-glasses, which translates into no danger of scratching the glasses;
- the laser marks into and not onto the material (compare with printing). Hence, the laser mark is durable, abrasion-proof, resistant to chemicals to the same extent to which the surface of the eye-glass has these properties;
- the laser marks are counterfeit-proof;
- no use of classical consumables such as dyes, liquids, solvents, particles (sand blasting) that require short-interval refill, replacement, exchange, disposal, etc. The marking process is clean. Corresponding work preparations, standstill times, cleaning times, etc. are dropped, labour costs are reduced;
- high marking speed.

Further examples for excimer laser glass marking include marking the heater symbol onto an electrically heated rear view mirror, whereby marking is accomplished via removal of the metallization (Fig. 3), as well as marking glass melting pots and micro marking diamonds.

**C. Structuring of glass**

There is no stride from glass marking to glass structuring. The structuring process can be considered as a special engraving. In principle, the laser system for structuring is identical to...
the laser marker described above (see Fig. 1). The only difference is that the mask does not contain marking information but the structuring pattern. The mask is de-magnified onto the workpiece by the working lens. Depending on the laser intensity, a laser pulse removes a layer of thickness between 0.1 to 0.5 \( \mu \text{m} \). The depth of the structure is adjusted by setting the number of laser pulses. Examples for glass structuring with excimer laser are microscope reticules, alignment marks, and blood-counting cells on the micrometer scale.

A highly interesting and topical application is writing Bragg gratings into optical fibres (Fig. 4 previous page). Through mask or interferometric techniques, a periodic laser intensity distribution is generated on the surface of the optical fibre. With a single intense excimer laser pulse, a grating can be written into the fibre. This process is applicable also during the fibre pulling process, a prerequisite for automated manufacturing on a high-volume industrial scale.

Light travelling along the fibre will be diffracted when it hits the grating, and reflection and outcoupling may occur. For any given grating, these diffraction effects depend on the wavelength of the signal light. Excimer laser-written optical fibre gratings can be applied in components such as lasers, amplifiers, reflectors, bandpass filters, noise reducers, wavelength multiplexers, and sensors for measuring temperature, pressure, stress, etc.

These fibre gratings have the potential to revolutionise the telecommunication and sensor industries.

**D. Drilling**

Drilling glass materials with excimer lasers is at its industrial dawn. At present, there are numerous promising investigations underway, among others, for the electronics industry. The task is drilling holes with diameters from 1 up to 100 \( \mu \text{m} \). The principle of glass drilling can be illustrated with the example of drilling nozzles for ink jet printer heads. As for marking, the mask technique is applied. The mask contains the complete drilling pattern for a multiple of printer heads. The mask is de-magnified onto the workpiece, a thin foil of polyimide. The hole diameter needed for up-to-date, high-resolution ink jet printers is down to 30 \( \mu \text{m} \) (Fig. 5). Drilling is not accomplished with a single laser pulse but with a train of pulses. Each laser pulse removes a 1 \( \mu \text{m} \) layer.

The process is photolytical. The main reasons for applying the excimer laser in ink-jet nozzle drilling are unsurpassed quality (edge sharpness, no burr, no melt or slag, no blistering, no cracks, no grooves, no discoloration), reproducibility, and process reliability.

Further drilling applications for excimer lasers are:
- holes in circuit boards (PCBs, PWBs, FPCs, multichip modules, etc.);
- flow channels in dosing systems;
- holes in the side of medical bilumen catheters (Fig. 6).

**E. Microtechniques**

The trend towards miniaturization does not stop at electronics. There is also significant interest in micro mechanical and micro optical components, and especially in micro components that combine electronic, mechanical and optical functions. An immense number of interesting applications for these components can be found in medical, chemistry, telecommunications, and sensor sectors.

The exceptional potential of the excimer laser in microprocessing is demonstrated in Figure 7 (following page): the ceramic gear (\( \text{Al}_2\text{O}_3 \)), diameter 120 \( \mu \text{m} \), thickness 600 \( \mu \text{m} \), was manufactured using the excimer laser mask technique. Despite the geometries and the...
critical material properties (high melting and evaporation temperature, hardness, brittleness, susceptibility to cracks) the quality of the gear is high. The workpiece surface shows slight melting, but thermal stress was restricted to the µm range. Micro cracks do not appear, a decrease of mechanical strength of the workpiece was not detectable.

The investment cost of a laser system for material processing is high, and excimer laser systems are no exceptions. Thus, laser processing of individual parts can be quite costly. Using the laser not only for production of the actual parts but also for masters to be used in a subsequent replication process can improve economies. Here, the LIGA technique offers a promising possibility for mass production of micro components. The principle of LIGA is indicated in Figure 8. A substrate (e.g. a silicon or titanium wafer) is coated with, for example, a polymer.

This coating is structured by excimer-laser mask techniques. The structured surface is coated with a thin metal layer which serves as an electrode in a subsequent electroplating process. After electroplating, flattening of the metal surface and removal of the substrate, the master is obtained.

This master is used as a mould insert for production of low-cost negative replicas. Figure 9 (page 334) shows a nickel master machined by Excimer-Laser LIGA: wall height 200 µm, channel width 20 µm. With techniques such as Excimer-Laser LIGA, low-cost mass production of micro parts will no longer be only a theory.
**F. Cleaning**

A special case of material removal is cleaning surfaces. The excimer laser beam is guided onto the surface to be cleaned and removes the pollution without affecting the base material. The mechanism of removal depends on the material/workpiece to be cleaned and the type of pollution. Some examples for removal mechanisms are:

- The pollution absorbs laser radiation, heats up and evaporates without any remains;
- The molecules of the pollution dissociate under the UV radiation. The fragments take up a larger volume than the starting molecules and therefore fly like an explosion out of the process zone;
- The surface to be cleaned is moistened by a liquid. The laser pulse removes the cleaning liquid locally. This causes a pressure wave, taking away locally the pollution from the surface.

Application examples are:

- **electronic industry**: cleaning LCDs, glass masks, wafers, single chips, electro-optical components, etc.;
- **optics**: removal of fingerprints, dust, grease, plastic residues from lenses, mirrors, gratings. Especially useful for cleaning telescope mirrors;
- **restoration**: removal of pollution, coatings, etc. from historical glasses such as church windows.

**Summary**

In the last five years, the excimer laser has increasingly gained importance in industrial manufacturing. Its outstanding features make it an interesting instrument for fine and microprocessing of glass materials. However, despite numerous actual applications, excimer-laser material processing is still in its early stages. The possibilities of this exciting technique are nowhere near being exhausted, and there is no telling how development will turn out.

*This article was first published in "Glastechnische Berichte, Glass Science and Technology", Vol. 70, 4/97 (April).*