December 2020

Application of Ultrafast and CO2 Lasers for Cutting Waveguides

Moez Haque

Saeid Rezaei

Victor Isbrucker

Application of Ultrafast and CO2 Lasers for Cutting Waveguides

ABSTRACT

Techniques for the cutting of waveguides from patterned glass wafers are described. Translation of an ultrafast laser beam across a wafer is performed to mark the wafer by forming a filament curtain that is aligned to the waveguide edge profile. Chucks are used to secure the wafer during marking and subsequent separation of the waveguides. The chucks include vacuum ports placed at selected locations for debris control around the cut edges. After marking, thermal shock is induced by CO2 laser absorption for breakage along the filament curtain and waveguide separation (singulation). An optical imaging system is used to calibrate the positional alignment of cutting profiles to the patterned wafer.

KEYWORDS

- Waveguide
- Wafer marking
- Singulation
- Ultrafast laser
- Carbon dioxide (CO2) laser
- Filamentation
- Filament curtain
- Picosecond laser
- Glass cutting
- Augmented reality (AR) headset

BACKGROUND

Display components of devices such as Augmented Reality (AR) or Virtual Reality (VR) headsets commonly include a waveguide to transmit an optical image signal from a projector to the eye. The waveguide is a thin (e.g., <1mm thick) glass piece that can be patterned using semiconductor or other fabrication processes. Multiple sets of waveguides are first patterned onto a wafer (e.g. 100mm - 300mm diameter), which are then cut to yield multiple waveguides.

The fragility and thinness of the wafer poses challenges for conventional glass cutting and dicing methods such as diamond scribing, plasma etching, traditional laser cutting, etc. to achieve an acceptable cutting quality. Since the physical dimensions of defects and edge roughness in conventional methods of cutting glass is on the order of the waveguide thickness, a risk of catastrophic fracturing during the cutting is increased. Additionally, the use of high refractive index glass with a relatively high additive concentration worsens wafer fragility. Fracture risk during cutting is further compounded by the presence of coatings on the wafer that can add stresses and bow the wafer. This can result in damage to the surrounding regions and/or waveguides during separation of a single waveguide from the wafer.

Conventional cutting methods limit choices in waveguide design due to constraints such as a minimum turning radius for cutting, as well as limit waveguide yield per wafer due to process-related spacing constraints between adjacent waveguides. A lower waveguide yield per wafer can increase the cost of waveguide production due to the high cost of wafer processing.

In addition, steps that follow conventional glass cutting methods such as polishing to remove chips, cracks, poor edge roughness, etc. are undesirable here because of the added processing time and costs associated with maintaining high cutting yield (e.g. physical contact risks waveguide breakage) and cleanliness (e.g. slurries and polishing debris risk cleanliness on the waveguide patterns and clear aperture).

DESCRIPTION

This disclosure describes techniques for cutting waveguides from patterned glass wafers. Per techniques of this disclosure, a waveguide cutting process utilizes an ultrafast laser to mark the wafer (marking) followed by separation of the individual waveguides using a carbon dioxide (CO2) laser (singulation).

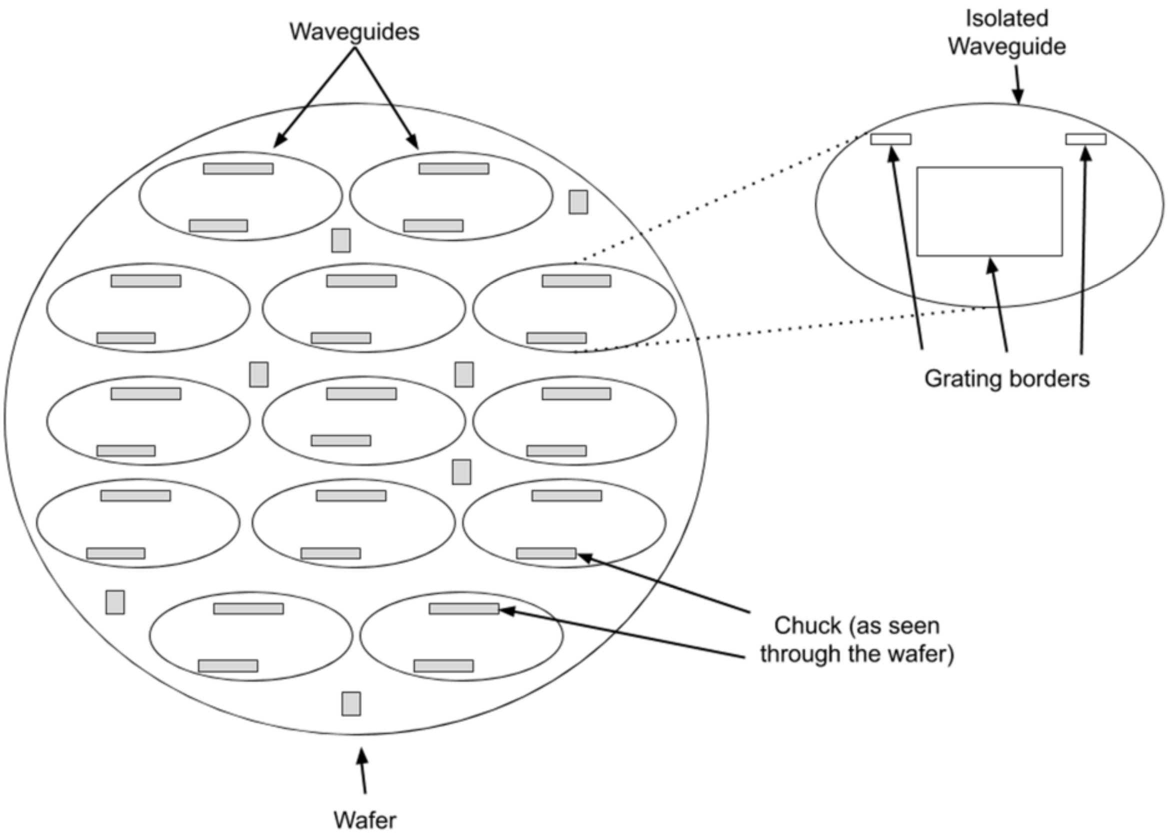

Fig. 1: Wafer with multiple waveguides prior to separation

Fig. 1 depicts an example patterned wafer that includes multiple waveguides laid out across the wafer. Each waveguide includes one or more gratings per specified optical requirements. Fig. 1 also depicts an example of chuck contact locations that are distributed over a supporting surface on which the wafer is placed, as seen through the wafer. While Fig. 1 illustrates each waveguide in the shape of an ellipse, the described techniques can be used for waveguides of any suitable shape.

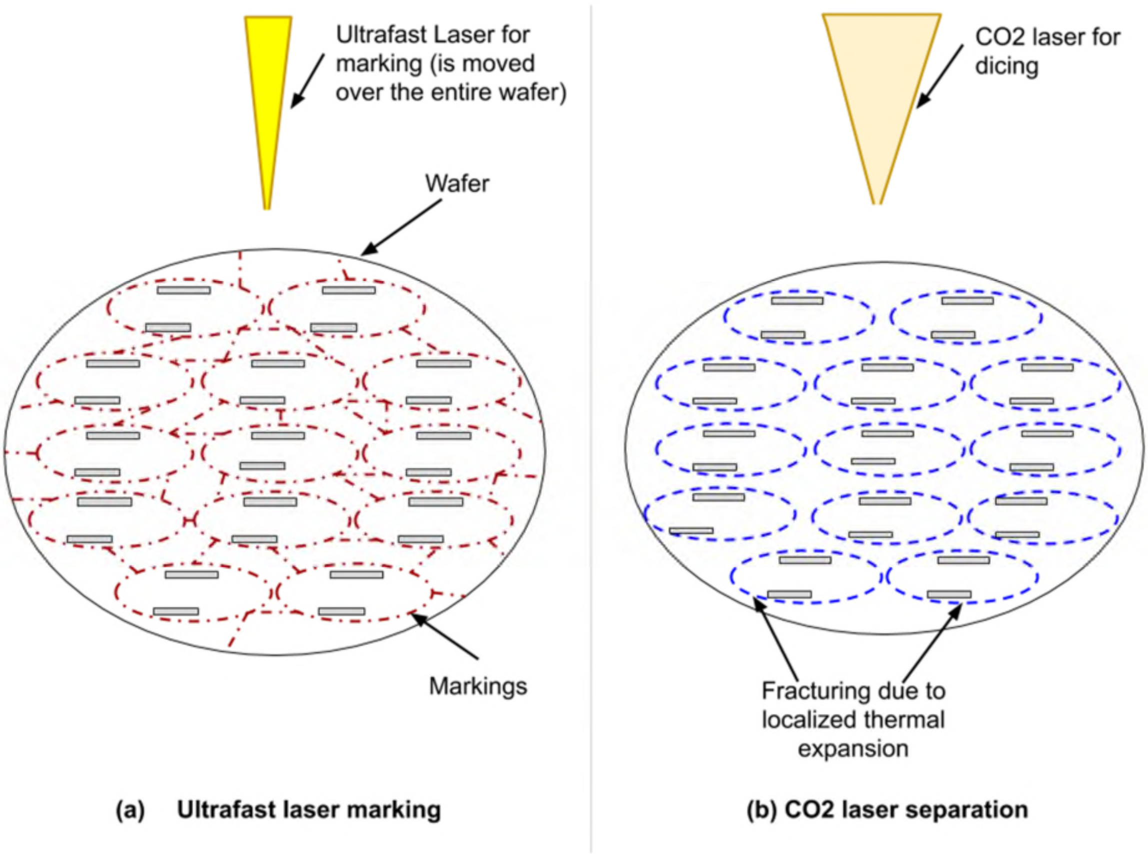

Fig. 2: (a) Ultrafast marking of a wafer; (b) waveguide separation using a CO_2 laser

Fig. 2 depicts an example of the cutting process for waveguides, per techniques of this disclosure. An ultrafast laser is utilized for marking a patterned wafer and to delineate the individual waveguide profiles (red dotted lines), as depicted in Fig. 2(a). Straight markings between adjacent waveguides, or peripheral waveguides to the wafer boundary, are also added to selectively divide the non-waveguide zones of the wafer (red dotted lines) for controlled dissection during singulation. The laser-glass interaction utilizes minimal mechanical contact, except to hold the wafer in place during the marking, thereby minimizing any risk of catastrophic fracture.

Ultrafast laser radiation with a wavelength that is transparent to glass is utilized for the marking to avoid linear absorption, thereby driving self-focusing and filamentation. The ultrafast laser parameters are selected such that the pulse duration and repetition rate minimize thermal effects in the glass (e.g., linear absorption, heat transfer), and a pulse peak intensity that is sufficiently high to drive nonlinear absorption in the glass (e.g. multiphoton ionization). This enables the marking of the wafer through its entire thickness by filamentation, thereby minimizing heat-affected zones, micro-cracks, and stresses in the waveguide and promotes waveguide durability after assembly into a device.

Each filament is created by a single ultrafast pulse that self-guides through the glass and ionizes the glass material towards eventual modification in a column-like shape. The laser beam is programmed to move across the wafer surface following the waveguide profile at each wafer location, leading to the formation of a filament curtain (a linear array of column-like modifications) with a constant filament periodicity (e.g., 5 micrometers) that is minimized to reduce edge roughness and aligned to the waveguide edge profile.

Chucks are utilized to hold the wafer in place during marking and subsequent separation of the waveguides. Accurate alignment of the wafer, e.g., by maintaining it in a flat position and avoiding bowing, is enabled by applying vacuum to select zones on the wafer. Maintaining a flat wafer surface that is aligned normal to the marking laser (filaments) is important for achieving a uniform cutting edge quality around the entire waveguide part, which prevents generation of potentially weak spots due to poor laser alignment that can otherwise cause cracks and lead to catastrophic fracturing.

Further to securing the wafer, the chuck includes vacuum ports placed at selected chuck locations to control debris fallout, e.g. potential thin film ablation during marking. This improves the cleanliness on the clear aperture of the waveguide. Air flow is also applied above the wafer for added cleanliness control.

During the marking processes, the patterned surface of the wafer faces downward towards the chuck, thereby avoiding any potential debris buildup on the top of the surface that would otherwise jeopardize the optical function of the patterns. All contact between the wafer and chuck occurs only at non-critical zones to again avoid jeopardizing the optical function of the waveguide.

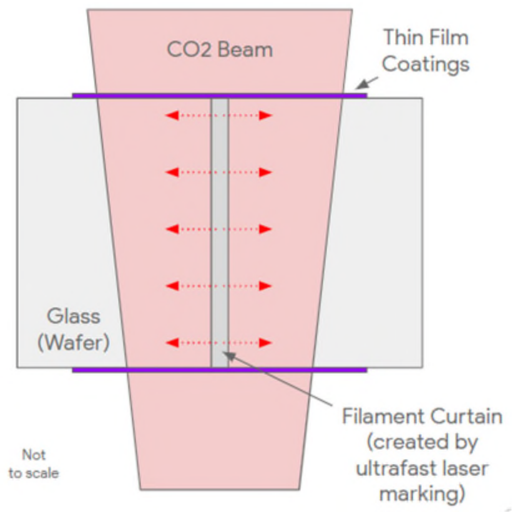

Fig. 3: Separation of waveguides using a CO2 laser

Fig. 3 is a schematic that illustrates separation of individual waveguides from a wafer using a CO2 laser, per techniques of this disclosure. After marking the wafer using an ultrafast laser, the wafer is placed under a CO2 laser for waveguide separation, as shown in Fig. 2(b). The

CO2 laser wavelength is absorbed by the glass, thereby inducing a thermal shock at and around the filament curtain.

Slight expansion and contraction of the glass in the non-marked regions is induced by the weak heating and cooling effects of the absorbed CO2 laser, without reaching a brittle limit of the unmarked glass. Within the filament curtain, the low thermal shock is sufficient to induce breakage along the glass regions modified by the markings and leads to waveguide separation along the filament curtain.

Further, during separation by the CO2 laser, a vacuum is applied by the chuck at select positions below the wafer to hold the waveguide parts in place while non-waveguide portions drop away. The waveguides are thereby isolated for pickup. Techniques of this disclosure enable efficient separation of individual waveguides that is not impeded by the presence of glass shards or larger glass pieces. No cracks or edge chips are observed after separation, and an edge surface roughness of $S_a < 0.001$ mm can be achieved, needing no additional edge treatments, e.g. mechanical edge polishing to achieve improved part durability.

Additionally, the cutting edge quality is unaffected by the presence of thin films or patterns on the wafer surface. When compared to conventional cutting methods that can commonly cause deterioration of the films, including film delamination, blistering, and ablation toward debris accumulation on the clear aperture, ultrafast marking and CO2 singulation together avoid deteriorating the functional performance of the waveguide as disclosed here.

In some implementations, an optical imaging system can be used to calibrate the positional alignment of the cutting profile to the patterned wafer. This provides an alignment precision that is limited only by the motion control accuracy and the filament diameter, thereby offering a positional precision of 0.003 mm (range equal to the filament diameter) and near-zero rotation.

The techniques of this disclosure can be utilized for the cutting of waveguides of superior quality that meet the required quality standards for shape, edge quality, durability, and cleanliness, e.g. for use in AR/VR headsets or other devices.

CONCLUSION

Techniques for the cutting of waveguides from patterned glass wafers are described. Translation of an ultrafast laser beam across a wafer is performed to mark the wafer by forming a curtain of filaments that follow the waveguide profile. Chucks are used to hold the wafer in place during marking and subsequent separation of the waveguides. Accurate alignment of the wafer is enabled by applying vacuum to select zones on the wafer. The chucks include vacuum ports placed at selected chuck locations for debris control. Thermal shock from CO2 laser absorption is utilized to induce breakage that leads to waveguide separation (singulation) along the filament curtain. An optical imaging system is used to calibrate the positional alignment of cutting profile to the patterned wafer.

REFERENCES

1. Muller, Dirk, “For Glass and Silicon Wafer Cutting, Shorter Pulse Widths Yield Better Results,” https://cn.coherent.com/assets/pdf/IndPhotonics_Micromachining_Glass_Cutting.pdf, accessed on 16 November, 2020.
2. “How to Cut Glass,” https://www.wikihow.com/Cut-Glass, accessed on 17 December 2020.
3. Chin, S. L., S. A. Hosseini, W. Liu, Q. Luo, F. Théberge, N. Aközbek, A. Becker, V. P. Kandidov, O. G. Kosareva, and Hartmut Schröder. "The propagation of powerful femtosecond laser pulses in opticalmedia: physics, applications, and new challenges." *Canadian Journal of Physics* 83, no. 9 (2005): 863-905.