phys. stat. sol. (c) **0**, No. 7, 2232–2235 (2003) / **DOI** 10.1002/pssc.200303548

Laser controlled thermocracking die separation technique for sapphire substrate based devices

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Received 10 April 2003, revised 15 August 2003, accepted 16 September 2003
Published online 26 November 2003

PACS 65.40.–b, 78.20.–e

The glass precise cutting by CO_2 laser appeared to be effective for sapphire wafer die separation. A standard sapphire wafer can be processed in 2 min, neither thinning, no final cleaving are needed. A commercial equipment LED chip cutting demonstrated no degradation after 5000 h of the LED test.

1 Introduction The traditional mechanical die separation is not well suited to sapphire substrate devices, mainly using *c*-oriented sapphire surfaces. Meanwhile the cutting process, described in this manuscript, for other sapphire surface orientations is effective as well. The laser ablation for cutting was successfully demonstrated by Emcore, K-Jet International Inc. and J. P. Sercel Associates Inc. companies [1]. They use a high power UV laser for sputtering grooves into the sapphire substrates, followed by conventional scribe and break methods. Compared with the mechanically scribing with a diamond tool the UV method increases die yields and wafer throughput and reduces the equipment operation and maintenance costs. Meanwhile the cost and the lifetime for the UV laser are still subject for further development. Moreover, the technique described in this paper allows to get rid of the fracturing machine cleaving and even the wafer thinning if needed. The quality of the cutting edge appeared to be effective mirrors for laser dies. We used for GaN-based LED wafers the Laser Controlled Thermocracking Die Separation Technique with the laser wavelength 10.2 μm. The Laser Controlled Thermocracking Technique (LCTCT) [2] is widely used for the precise cutting for flat panel display production, including liquid crystal displays and plasma display panels [3].

2 Laser controlled thermocracking technique physics The main feature of LCTCT is the appearance of the separation crack caused by two efforts – thermal positive tension due to laser surface heating and thermal negative tension due to the local cooling the heated zone by the cold agent. In this method the surface of a sapphire wafer is heated by a laser beam of radiation at some wavelength. Some of the beam energy is reflected, while most of it is absorbed and released as heat in a thin surface layer, as thick as the laser wavelength. The compressive stress produced in the heated layer does not result in sapphire splitting. Further propagation of the heat into the body corresponds to thermal conduction. The splitting of the wafer occurs as a considerable volume of the sapphire has been heated up, and the thermally induced stresses exceed its tensile strength. When a crack starts to form, the point of the laser beam incidence has been already displaced from the edge of the wafer. Thus the evolution and propagation of the crack lags behind the point of the laser spot movement.

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The laser beam power increasing may overheat the sapphire and longitudinal and transverse microcracks along the heating line will appear. To avoid this the method of forming in the wafer surface a blind crack of specified depth and direction includes the steps of the effecting relative movement between the body and an elliptical target area at which a beam of coherent radiation impinges on the surface along the intended direction of the crack. A stream of fluid coolant is directed at a point of the heated surface which is on the intended line of the crack, and which is displaced downstream from the target area by a chosen distance. The energy of the elliptical beam of the coherent radiation is controlled so that it heats the surface to a temperature below the damaging point of the wafer materials, so there is no material ablation caused by the CO_2 laser at all.

3 Results Further developments of the LCTCT allow implementing this technique for sapphire substrates [4]. Figure 1 shows the comparison between CO_2 and UV laser cutting edges. Figure 1d demonstrates the traces of the UV laser. We can cut the substrate through with mirror-like cutting edge quality and no need for final cleaving. A number of special methods and optical systems were implemented to get rid of die thermal degradation and have symmetry in temperature and mechanical tension distribution. The GaN-based LED dies separated by LCLCT demonstrated no cutting damages. The LED chips with sizes of 0.25×0.25 mm^2 and 1.0×1.0 mm^2 after LCTCT demonstrated no cutting caused degradation after 5000 h. The lifetime test demonstrated less than 15% luminous intensity decrease at the testing current of about 20 mA. This luminous intensity decrease level demonstrates the nature of the LED de-

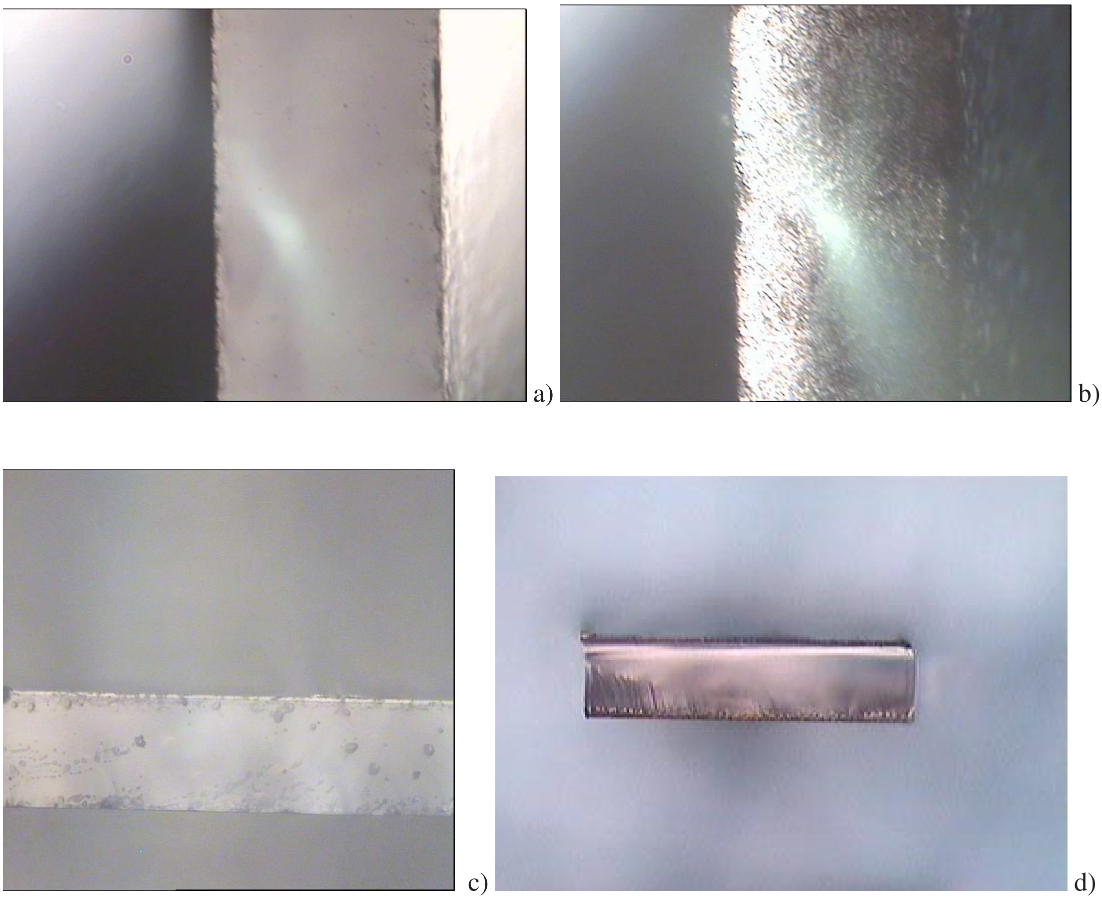
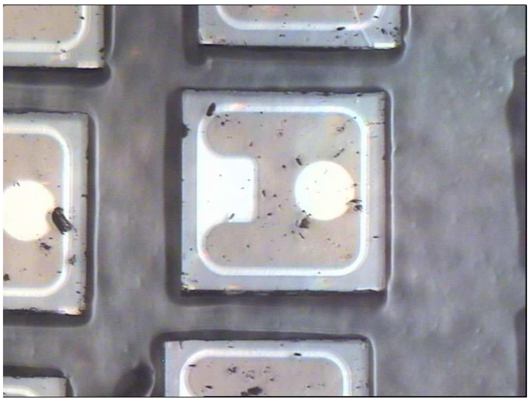
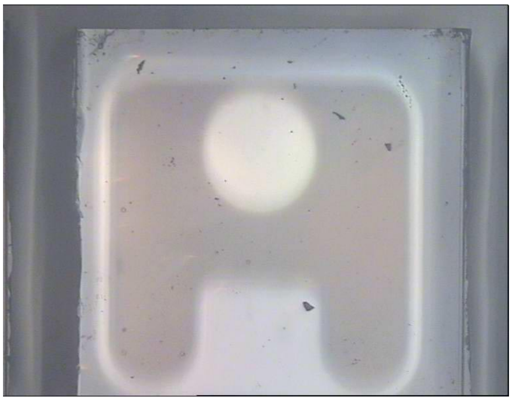


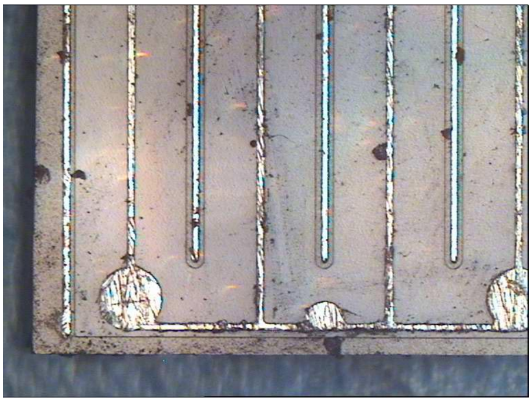
Fig. 1 (online colour at: www.interscience.wiley.com) Comparison between CO_2 and UV laser cutting. The samples a) and c) are after CO_2 laser cutting; samples b) and d) after UV laser cutting. a), b) scales 1:100; c), d) scales 1:50.



a)



b)



c)

Fig. 2 (online colour at: www.interscience.wiley.com) LED chips after CO_2 laser cutting – a) and b) 0.25 × 0.25 mm^2, c) 1.0 × 1.0 mm^2. a), c) scales 1 : 100, b) scale 1 : 200.

sign itself – not the cutting failure. Actually the cutting damages are objects of further researches. The actual cutting width is less the 0.001 mm and there is no damaged area on the chip edge – so the quantity of the chips successfully produced from the wafer will be increased. Figure 2 shows the LED chips after CO_2 laser cutting. The yield is about 100% if the cutting parameters are properly determined. The sapphire wafers with standard thicknesses were properly processed without neither thinning nor cleaving operations. All these LCTCT technology advantages should be taken into the economic considerations.

A commercial equipment, Fig. 3, has been developed and produced for sapphire substrate based device die separation by LCLCT. The parameters are given in Table 1 in comparison with mechanical and UV-laser cutting parameters.

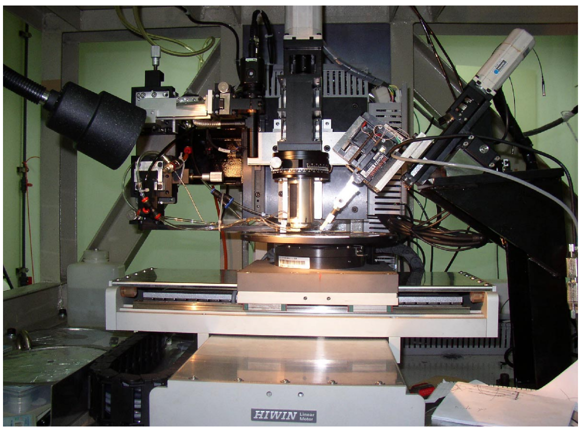


Fig. 3 (online colour at: www.interscience.wiley.com) Cutting head of the commercial equipment with the following parameters: laser type – CO_2; laser power – 100 W; equipment size 1500 × 1700 × 2250 mm; equipment weight – 1500 kg; power supply – 2.5 kW.

Table 1 A comparison of process economics between mechanical, UV and CO_2 laser scribing.

	diamond scribing [1]	UV laser [1]	CO_2 laser
cut width, μm	>100	< 5	< 1
cut depth, μm	30	30	wafer thickness
2″ LED wafer dicing time:	1 h	5 min	2 min
die yield, %	< 90	>99	>99
operating cost ($/wafer)	80	< 2	< 0.5
uptime, %	90	>99	>99
process automation	manual	automatic	automatic

4 Conclusion Precise cutting by CO_2 lasers appears to be effective for sapphire wafer die separation. It is effective both for *c*-oriented surface device sapphire substrates and other orientations. In comparison with the traditional diamond scribing and even with the UV laser methods the LCLCT allows to cut the wafers excluding machine cleaving and wafer thinning. The cutting edge appeared to be high quality mirrors for laser dies. The wafer dicing time of about 2 min, the die yield more then 99% and low operating cost demonstrate the economic effectiveness of LCLCT. Current research and development targets are SiC and GaN wafers.

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