Simulation of laser splitting of bilayer structures made of silicon wafers and glass substrates

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Abstract
The paper presents the results of a finite-element simulation of the laser splitting process of bilayer structures of monocrystalline silicon and glass under the influence of laser beams with wavelengths equal to 0.808 μm and 10.6 μm and a refrigerant on the workpiece. The calculation of thermoelastic fields formed in a bilayer wafer as a result of laser heating was performed for three cuts of silicon crystals, i.e. (100), (110), (111). The outcomes of this research can be used to optimize the process of laser separation of bilayer structures of monocrystalline silicon and glass.

Introduction
The main methods of separating glass products and instrument wafers into crystals include: cutting with diamond disks, mechanical and laser scribing [1 – 3]. One of the effective ways to cut silicate glasses and monocrystalline silicon is laser splitting [1 – 5]. In some cases, the successful implementation of laser splitting technologies for silicon wafers and glass products can be achieved by using double-beam processing methods [7 – 10]. The use of bilayer structures made of monocrystalline silicon and glass has become widespread in the manufacture of semiconductor microelectromechanical devices [2, 11]. Paper [2] provides a study of the laser splitting process of bilayer structures made of silicon and glass via a laser beam with a wavelength of 1.06 μm. Paper [10] presents a study when the workpiece was exposed to laser beams with wavelengths equal to 1.06 μm and 10.6 μm and a refrigerant. The current paper demonstrates the results of finite element simulation of laser splitting of similar bilayer structures under laser heating with beams with wavelengths equal to 0.808 μm and 10.6 μm and exposure to a refrigerant.

Numerical modeling

The finite-element modeling of the laser splitting process of bilayer structures made of monocrystalline silicon and glass was carried out within the framework of an uncoupled thermoelasticity problem in the quasi-static formulation using the ANSYS program. For comparative analysis, calculations of the thermoelastic field distribution were performed for six spatial variants of laser and refrigerant exposure zones. Thermoelastic fields in the bilayer structure for each of the six spatial variants of the laser and refrigerant exposure zones were calculated for six different variants, taking into account the anisotropy of the silicon layer, i.e. I a is the analysis of the (100) cut when cutting in the [001] direction; I b is the (100) cut analysis when cutting in the [011] direction; II a is the (110) cut analysis when cutting in the direction $[1\bar{1}0]$; II b is the analysis of the (110) cut when cutting in the [001] direction; II c is the (110) cut analysis, when cutting in the $[1\bar{1}1]$ direction, III is the analysis of the (111) cut, when cutting in the $[1\bar{1}0]$ direction.

Results of modeling and their discussion

Figure 1 shows the distribution of temperature fields and fields of thermoelastic stresses formed in a bilayer structure when cutting in the [001] direction of the (100) cut of monocrystalline silicon under sequential laser heating with beams with wavelengths equal to 0.808 μm and 10.6 μm and the influence of a refrigerant from the side of monocrystalline silicon. The maximum temperature values are in the range necessary for the realization of brittle fracture of the bilayer wafer under the action of thermoelastic stresses. The analysis of the spatial configuration of the boundary between tensile and compression stresses in the bilayer structures in the treatment zone (see isosurfaces at σ_{yy}=0), makes it possible to predict the success of crack propagation in both layers of the bilayer structure. In this case, the most effective of the six calculated treatment options seems to be the use of laser splitting of the bilayer structure in a sequential double-beam laser heating and exposure to the refrigerant from the side of the monocrystalline silicon.

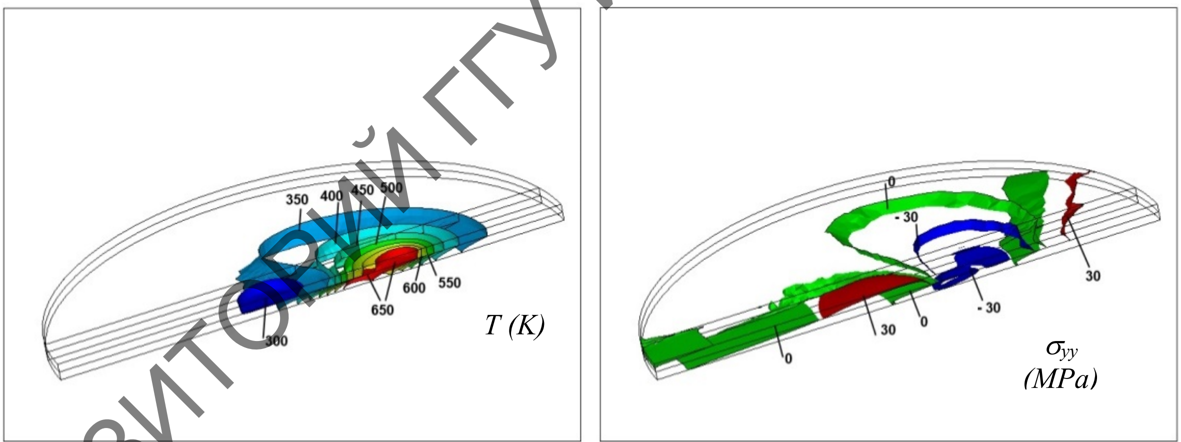

Fig. 1. Distribution of temperature T (K) and stresses σ_{yy} (MPa) in the volume of the processed bilayer sample during double-beam treatment from the side of the monocrystalline silicon

Conclusion

The results obtained show the necessity to take into account the anisotropy of elastic properties of monocrystalline silicon when choosing the parameters of laser splitting of bilayer structures. The paper shows the feasibility of implementing laser splitting of a bilayer structure with sequential laser heating and exposure to a refrigerant from the side of monocrystalline silicon.

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