"NEXCERA", Zero Thermal Expansion Ceramic for Ultra Precision Applications

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1. Introduction

NEXCERA, a cordierite ($2MgO$-$2Al_2O_3$-$5SiO_2$) based polycrystalline ceramic has been developed as a cutting-edge material having both an extremely low thermal expansion coefficient and superior mechanical properties. NEXCERA differs fundamentally from conventional low thermal expansion glass (LTEG) in consisting of a kind of the crystal and slight amorphous phases along grain boundaries. Accordingly, NEXCERA also has high dimensional stability for long-term passage and temperature changes as compared to LTEG [1,2]. Taking advantage of these features, NEXCERA is used as calibration tools and primary standards in the precision metrology field requiring high accuracy, in addition to structural components of steppers for LSI lithography [3]. The present work has been conducted to evaluate the advantage of NEXCERA as an optical reflecting mirror through the manufacture of ultra light-weight boxed structures.

2. The Manufacturing Process of Mirrors

Mixed powders of cordierite and sintering additives were ball-milled together with organic binder and water. The slurry thus obtained was dried to granulated powder, and then isostatically pressed into chalk-like blocks. The compressed blocks were machined into disk-shaped top-plates and ribbed bodies of 401 mm in diameter and 83 mm in height by making use of a machining center equipped with cutting tools. The ribbed bodies were once dewaxed at 350 °C in air, and then sintered at 1360 °C in an Ar-gas flow atmosphere. The sintered top-plates and ribbed bodies were ground using diamond wheels respectively, and then bonded by the diffusion method. After bonding, the hollow bodies were ground, and finally mirror surfaces were polished to fine finishes.

3. Characteristics of NEXCERA

Table 1 compares NEXCERA and conventional LTEG [4] in terms of various characteristics. NEXCERA has an extremely small thermal expansion coefficient of 0.03 ppm/K equal to that of LTEG at room temperature. The specific rigidity, representing the dgree of weight reduction, which is the amount of Young's modulus divided by bulk density, is superior to that of LTEG. The disk specimen of 150 mm in diameter and 30 mm in thickness was polished with diamond slurry and cerium oxide slurry, as shown in Fig. 1(a). The pore-less microstructure achieved by the polishing found to be an extremely smooth surface with an averaged-roughness (Ra) of 0.77 nm and a flatness of less than λ/10: 52 nm, as revealed in Fig. 1(b). The reflectivity of deposited aluminum on the corresponding specimen was 99 % for a dielectric multi-layer mirror coating, being preferable to an optical mirror. Thus, the present authors confirm that NEXCERA is sufficiently applicable for a reflecting mirror with high accuracy.

Table 1 The comparison of characteristics of NEXCERA and LTEG [4].

		NEXCERA	LTEG
Bulk Density	g/cm^3	2.5	2.53
Young's Modulus	GPa	130	90
Specific rigidity	$GPa \cdot cm^3/g$	54	36
Poisson's Ratio	—	0.30	0.24
Flexural Strength	MPa	210	—
Fracture Toughness (SEPB)	$MPam^{1/2}$	1.2	—
Hardness HV (98N)	GPa	8.0 (Vickers)	6.0 (Knoop)
Thermal Expansion Coefficient	$\times 10^{-6}/K$ (23℃)	0 ± 0.03	0 ± 0.02
Thermal Conductivity (23℃)	$W/m \cdot K$	3.7	—
Specific Heat	$J/g \cdot K$	0.83	—

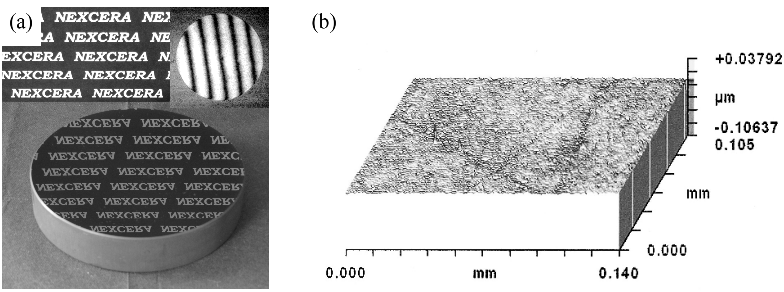
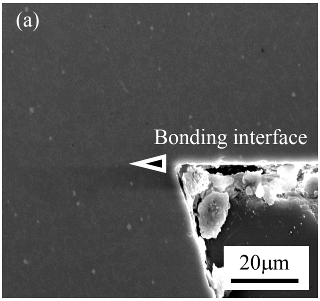


Fig. 1 The polished disk specimen with the interference fringe (a) and the corresponding surface roughness (b).

4. Bonding Properties

The ultra light-weight mirror can be attained by making top-plates and ribbed bodies bond together to form boxed structures. Figure 2(a) shows scanning electron microscope (SEM, S-2460N, Hitachi, Japan) image of the bonding interface by the diffusion method. No defect or reaction layer is recognized around the interface. There is practically no difference between the bulk portion and the bonding interface in the flexural strength, as revealed in the bending test in Fig. 2(b). The boxed structure manufactured through the diffusion method is therefore applicable for the mirror requiring high accuracy.



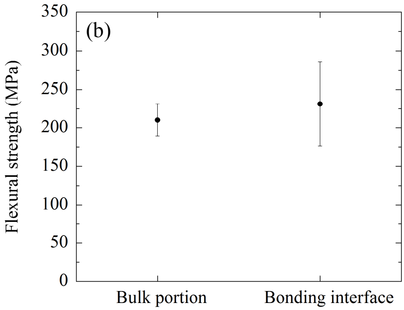


Fig. 2 SEM micrograph of the bonding interface (a) and a comparison of the flexural strength of the bulk portion and the bonding interface (b).

5. Ultra Light-Weight Boxed Mirrors

Unlike common LTEG, compressed compacts of NEXCERA can be easily machined to ribbed bodies in near-net shapes before sintering. Figure 3 shows the ribbed bodies after sintering, with two types of a schematic arrangement such as concentric and hexagonal cell. The details of the mirrors bonded top-plates and ribbed bodies are as follows; 340mm in diameter, 70mm in height, 3mm in rib thickness, 55mm in rib depth, 10mm in thickness on mirror side and 5.4kg in weight. Ultrasonic microscope characterized bonding quality of the mirror, as shown in Fig. 4. The color uniformity along rib arrangements indicates a perfect bonding without macroscopic defects. To confirm structural properties, finite element method (FEM) calculations were carried out regarding with the dead weight deformation if the mirrors were supported horizontally on three points around the perimeter, being extremely severe conditions, as illustrated in Fig. 5. The small calculated deformations of around 40nm were found for the mirrors of NEXCERA including both ribbed types, in compared with these of around 60nm for LTEG. The results of surface finishes for actual mirrors will be presented at the conference, which include averaged-roughness, flatness and dead weight deformations.

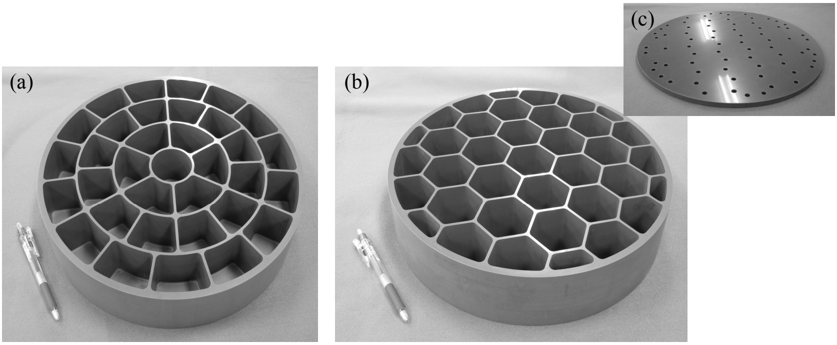


Fig. 3 Two types of ribbed bodies after sintering with concentric cell arrangement (a) and hexagonal one (b), and the top-plate after sintering (c).

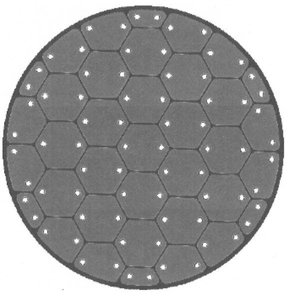


Fig. 4 The ultrasonic microscope image of the bonded mirror.

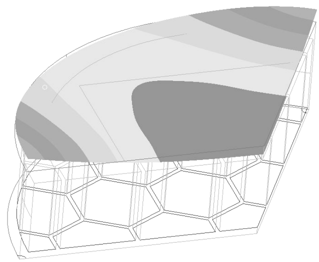


Fig. 5 FEM calculation regarding with the dead weight deformation

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