초정밀 단일점 다이아몬드 터닝을 이용한 비구면 금속 부반사경 가공

Ultra-precision single point diamond turning (SPDT) on an aspheric metal secondary mirror

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A 110 mm diameter aspheric metal secondary mirror for a test model of an earth observation satellite camera was fabricated by ultra-precision single point diamond turning (SPDT). Without a conventional polishing process, the surface texture of R_a=2.8 nm, and the form error of R_a=0.05 λ has been stably achieved in a laboratory condition.

For both ground based and space-borne telescopes, historically glass mirrors had their golden era with the improvements of glass ceramics of low coefficient of thermal expansion (CTE) or with the developments of new techniques such as lightweighting. It had been believed that it is better to reduce CTE as much as possible than to obtain a material in which the temperature reaches equilibrium naturally and quickly. However, gradually Aluminum-alloy mirrors are being considered as attractive candidates in terms of excellent thermal diffusivity, homogeneity, and cost and delivery time from positive experiences around the world.[(1), (2)] In case of an all-metal design telescope, the diffusive thermal characteristics can yield a better homogeneous temperature within the telescope, reaching the ambient temperature much faster, and possibly eliminating the risk of thermal gradients and the change of optical design.

Aluminum alloy for mirror substrates is known to be easily machinable, but not polishable due to its ductility. A harder material, Ni, is usually electrolessly coated on an Al substrate to increase the surface hardness for optical polishing. This presentation reports that the use of an ultra-precision SPDT machine on Al alloy surfaces, without any further polishing, enables the fabrication of near polished optical surfaces. Two main issues in optics fabrication, surface figure and surface texture were investigated.

A bear Al alloy substrate was roughly machined into a sphere, and then ultra-precision machined into the best-fit sphere. The best-fit sphere was then ultra-precision machined into the target asphere. Firstly, the stability of the aspheric surface figure on the bear Al alloy substrate was measured with a stylus profilometer over time in the laboratory environment. The absolute average figure error stayed consistently below 0.05 λ over 5 days time, which satisfies the designed tolerance. Figure 1 shows a profile of the asphere, where y=0 line represents the target conic section asphere, and the absolute average figure error is less than 0.03 λ.

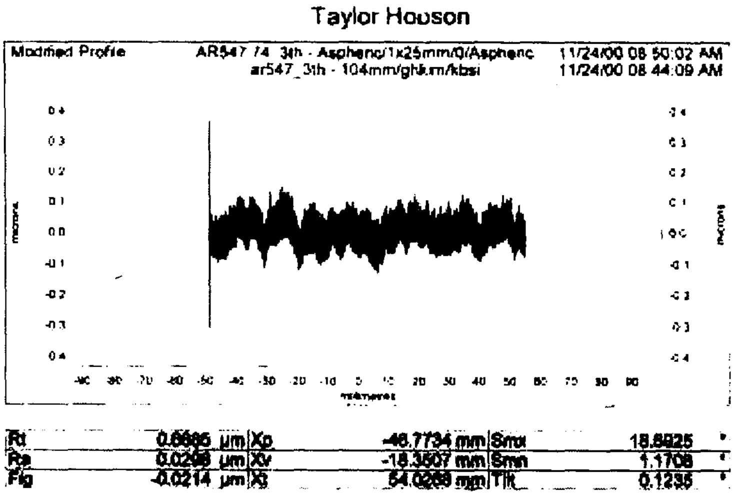

Fig. 1. The figure of a metal convex aspheric mirror measured after SPDT machining

As for the surface roughness, a bear Al alloy surface and an electroless-Ni coated surface were aspherised by SPDT and then the surface texture Ra values were measured with a microscope interferometer. Figure 2 shows the R_a of a bear Al alloy is less than 5 nm, but R_a of an electroless-Ni coated surface is less than 3 nm, which is near a pitch tool polished surface of glass-ceramic mirror.

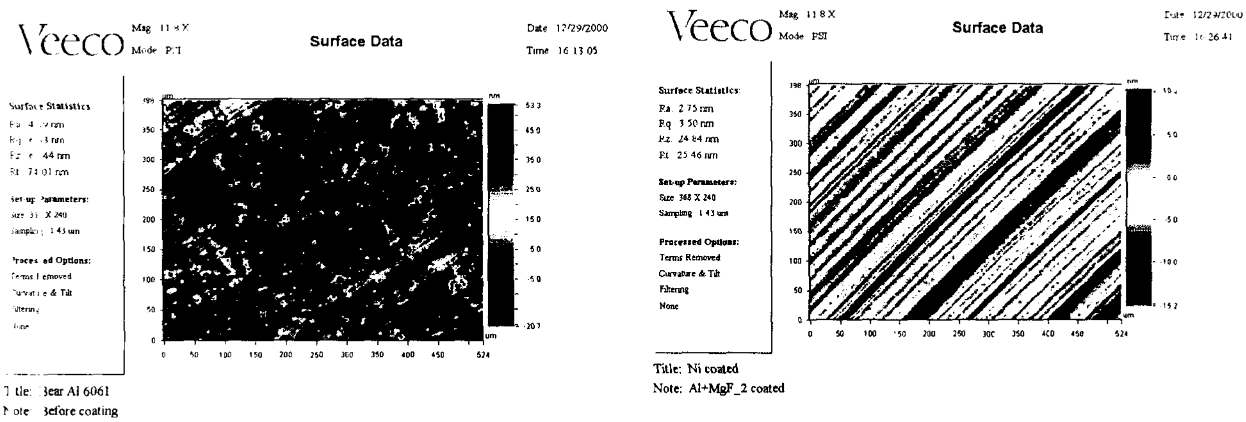

Fig. 2. Surface texture measurements of ultra-precision single point diamond turned bear Al alloy and electroless-Ni coated metal mirror surfaces

In conclusion, this work shows the feasibility of a metal mirror for telescopes, in terms of the figure error stability and the surface texture; particularly electroless-Ni coated Al alloy showed near pitch polishing surface texture quality. Further work remains on thermal cycle analysis and experiment of space environment, and the assembly integration test of the whole metal telescope including the metal primary mirror and metering structure for the evaluation of the telescope system.

1. Rozelot, J. P., Proc. Int. Workshop on Mirror Substrate Alternatives, pp. 3-17, (1995)
2. Altmann, J., Egle, W. J., et al, Proc. SPIE, pp.559-566, (2000)