New nickel plated metal mirrors utilizing meltspun aluminium silicon alloy

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Abstract

High performance metal mirrors require a polishable surface layer to achieve the demands for the UV/VIS wavelengths. The amorphous electroless nickel (NiP) offers the possibility for the manufacturing of mirrors with excellent figure and roughness [1]. However, the mirror substrate material particularly aluminium 6061 has a significant mismatch in the coefficient of thermal expansion (CTE). Due to temperature changes, the bimetallic effect introduces figure distortions. The new idea is to match the CTE by using a meltspun aluminium alloy with a high silicon contents (≥ 40 %) as mirror substrate [2]. Besides the matching of the CTE, the specific stiffness shows a considerable increase compared to Al6061.

1 Introduction

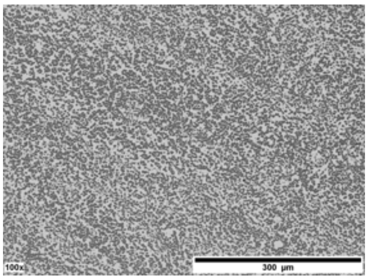
Aluminium 6061 for scientific instrumentation and copper for laser application are common metal mirror materials. However, turning marks and the material microstructure cause diffraction effects and scattered light becomes more and more a problem. Micro roughness and figure deviation can be significant reduced by polishing a NiP-plating. Figure deviation below 100 nm p.-v. @ $(100\ mm)^2$ and micro roughness < 1 nm r.m.s. open up the visible and ultra violet spectral range. A number of challenging applications demonstrate the superior optical performance of nickel plated and post-polished mirrors [1, 3]. Besides reaching a high surface quality structural requirements such as: extreme light weight, athermal design, low-stress mounting techniques, as well as defined reference structures can be advantageously realized. As the main issue remains the behaviour under thermal load. Because of the CTE-mismatch between the mirror substrate, (Al6061, ~23 ppm/K) and electroless NiP (CTE ~12.5 ppm/K) the bimetallic effect leads to distortion of the optical surface. Using an alloy with a silicon contents ≥ 40 % the CTE mismatch can be reduced to less than 0.5 ppm/K.

Material	CTE [ppm/K]	Density [g/cm3]	E-Mod. [GPa]	**ΔCTE vs. NiP**
AlSi40	**13**	**2.55**	**100**	**< 0.5 ppm/K**
Al6061	23	2.7	69	~ 10 ppm/K

Table 1: Substrate materials for nickel plated high quality mirrors

2 Rapidly solidified aluminium alloys with high silicon content

Rapidly solidified aluminium alloys offer several advantages compared to conventional alloys: finer microstructure, higher percentage solute elements and improved mechanical properties. When meltspinning is used for rapid solidification, with a cooling speed of about 10^6K/s, these advantages become more pronounced [4]. The alloy micro-structure is much finer than can be realized with alternative solidification techniques. The material with a chemical composition of 40wt%Si and 60wt%Al shows a very homogeneous microstructure without pores, at 100% density (Figure 1).



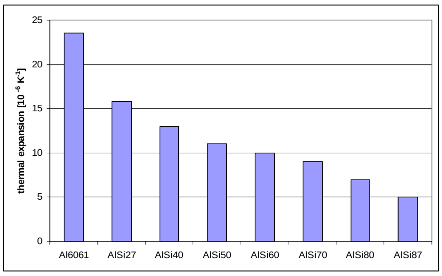


Figure 1: Microstructure of AlSi40   Figure 2: Possibilities for “tuning” the CTE

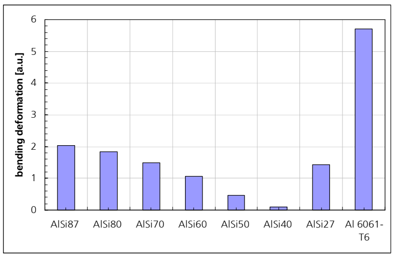
The CTE 13 ppm/K of AlSi40 is lower than for classical aluminium alloys and becomes similar to the CTE of NiP. It is noted that the CTE for Al-Si alloys with high Si%, is due roughly to a material composed of a silicon phase and an aluminium phase and can tuned over a wide range by varying the silicon content.

3 Bimetallic bending

The scaling behaviour of the deformation due to the CTE mismatch of a simple bi-metallic plate is given by the following relation:

$\text{Deformation} \sim \Delta\text{CTE} * \text{Thickness}_{\text{NiP}} * E_{\text{NiPlayer}} / (E_{\text{substrate}} * \text{Thickness}_{\text{substrate}}^2)$

Both the higher modulus of AlSi40 compared to standard aluminium and the small CTE mismatch between AlSi40 and NiP have a positive impact on reducing the bimetallic bending. This benefit is illustrated in figure 3.



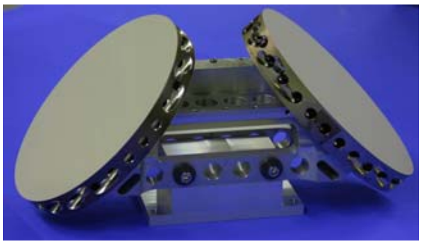
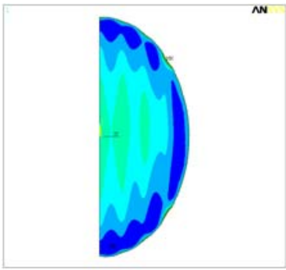


Figure 3 (left): Normalized bending deformation for aluminium plates with different composition. Parameters: 20 mm Al-alloy, 0.1 mm NiP plating
Figure 4 (right): Piston Mirror for the LBT (instrument LINC/NIRVANA)

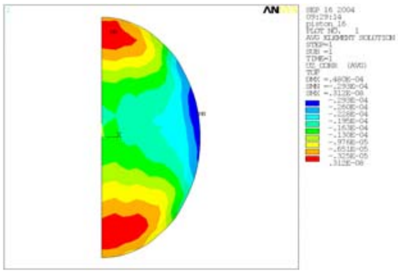
4 NiP plated mirrors with AlSi40 substrate material

4.1 Piston Mirror for the Large Binocular Telescope (LBT)

The Piston Mirror combines the two beam lines of the LBT. It is also used for phase correction by moving due to a piezo actuator. In a temperature range from –15° C to 25° C a figure deviation less than λ/10 p.-v. @ 632 nm is required. Besides the reduction of the figure distortion by using AlSi40 an athermal and light weighted design including the piezo-actuator-table (steel) was realized. After post polishing and figuring the final mirror quality was 30 nm p.-v. and 4.5 nm r.m.s. (figure deviation) with a micro roughness of 0.5 nm r.m.s..



Design: Al6061 with 25 µm NiP-layer @ ΔT=25 K
Mirror mass: 1010 g
Figure deviation: 66 nm p.-v.

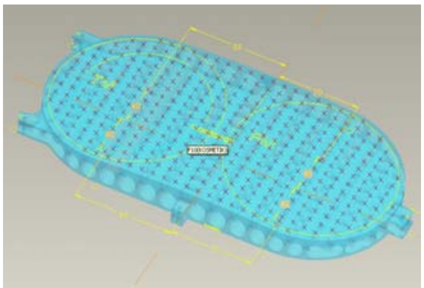


Design: AlSi40 with 25 µm NiP-layer @ ΔT=25 K
Mirror mass: 890 g
Figure deviation: 39 nm p.-v.

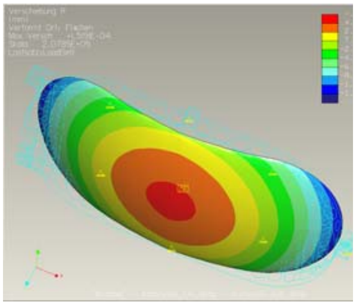
Figure 5 : FEM simulation of bimetallic bending using different substate materials

4.2 Light weight mirrors for METimage instrument

For the METimage multi-spectral imaging radiometer a novel rotating telescope covering the spectral range from VIS to TIR is under development. The athermal design is completely carried out by using the low thermal expansion alloy AlSi40.



Size: 306 mm x 152 mm x 28 mm.
Mass: 1629 g
Reduction of mass: 39 %.



Radius deviation: 160 nm @ ΔT=10 K
with 50 µm NiP on AlSi40

Figure 6: Light weight design and FEM simulation of the main mirror

For all mirrors FEM simulations in respect to gravity and bimetallic deformation were carried out. As an example figure 6 illustrates the change of the curvature applying a thermal load of 10 K into the main mirror. Within a breadboard study both, the aspherical main mirror and the secondary freeform mirror, were realized with a surface quality of less than 200 nm p.-v. and with a micro roughness of 1 nm r.m.s..

5 Conclusion

The presented paper describes the reduction of the bimetallic bending of Nickel plated mirrors by the use of novel aluminium - silicon alloys is described. Physical properties of the low thermal expansion alloy are pointed out. Finite elements simulations of light weight mirrors show the advantages regarding temperature change, plating uniformity and specific stiffness.

6 Acknowledgement

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