Durable silver coating for Kepler Space Telescope primary mirror

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ABSTRACT

A durable silver coating was developed and applied to the Kepler Space Telescope primary mirror. The coating was manufactured by an ion-assisted evaporation process and coating uniformity was better than 30-nm PTV over the 1.4-m mirror aperture. The protection scheme for silver was devised and patented twelve years ago by Lawrence Livermore National Laboratory (LLNL) in the United States[1]. An interference coating was added to the basic protected silver design, to enhance the reflectance from 400-nm to the near infrared.

Keywords: Silver coating, evaporation, ion assisted, durable, Kepler, mirror

1. INTRODUCTION

NASA's Kepler Mission will utilize a space telescope to detect planets in solar systems many light years from Earth. In order to produce a system with enough sensitivity to detect the smaller, Earth-like planets as they pass in front their host stars, a very high reflectance coating was sought. A protected and enhanced silver coating was selected to satisfy this need.

In 2001, Surface Optics Corporation (SOC) designed and fabricated a 3.3-meter vacuum chamber equipped with an evaporation system mounted on a computer-controlled, movable stage. By evaporating from many positions within the chamber, exceptionally flat coatings may be deposited on large, curved surfaces. In SOC's ion assisted evaporation process (IAD), only a relatively small portion of a large substrate is coated at any given time, therefore, an ion flux sufficient to produce very dense coatings is readily generated with a single End-Hall ion source. This method also provides a means of tightly controlling the arrival ratio of atoms to ions at the substrate surface.

In the mid 90's, a durable silver coating formulation was developed at LLNL using a reactive sputter coating process. In 2004, SOC demonstrated that the nitride compounds used by LLNL to protect silver may be produced by IAD, as an alternative to sputtering.

Since an evaporation source may be positioned further from the substrate than a typical sputter target, the physical deposition conditions are less affected by irregularities in substrate geometry[2]. Therefore, an evaporation process may be preferable for large, uniquely curved substrates[3]. Alternatively, custom shaped sputter targets, which follow the contour of a particular substrate design may eliminate this issue, but at considerable additional cost[4].

In June of 2007, SOC's silver coating process was space-qualified and applied to the Kepler mirror.

2. PROTECTED SILVER COATING DESIGN

The LLNL protected silver coating relies on the application of two thin nitride layers placed on top of the silver. These layers protect the silver and prevent tarnishing. As described in the LLNL patent, the layers are created by sputtering nickel-chromium and silicon, respectively, in the presence of ionized nitrogen[1,3]. The nitride layers provide both chemical and physical barriers, which prevent silver from reacting with ions from the atmosphere[1,3,4,5,6]. Figure 1 shows the basic LLNL protection scheme.

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Si_3N_4
Ni-CrN_x
Ag
Ni-CrN_x
Mirror Surface

Figure 1: LLNL's Protected Silver Design.

In SOC's IAD process, the nickel-chromium and silicon are evaporated, rather than sputtered, also in the presence of ionized nitrogen. Because nickel-chromium nitride (Ni-CrNx) is highly absorbing in the blue and UV regions of the spectrum, it is desirable to minimize the thickness of this layer, to that which is required for adequate silver protection.

Figure 2 shows the effect of increasing Ni-CrNx thickness on reflectivity. In order to compensate for the loss in reflectivity from this layer, an interference coating comprised of high and low index oxide layers was applied after the nitride protection layers. These hard, metal-oxide layers also improved the abrasion resistance of the coating. Figure 3 shows a sketch of the final nine-layer coating design.

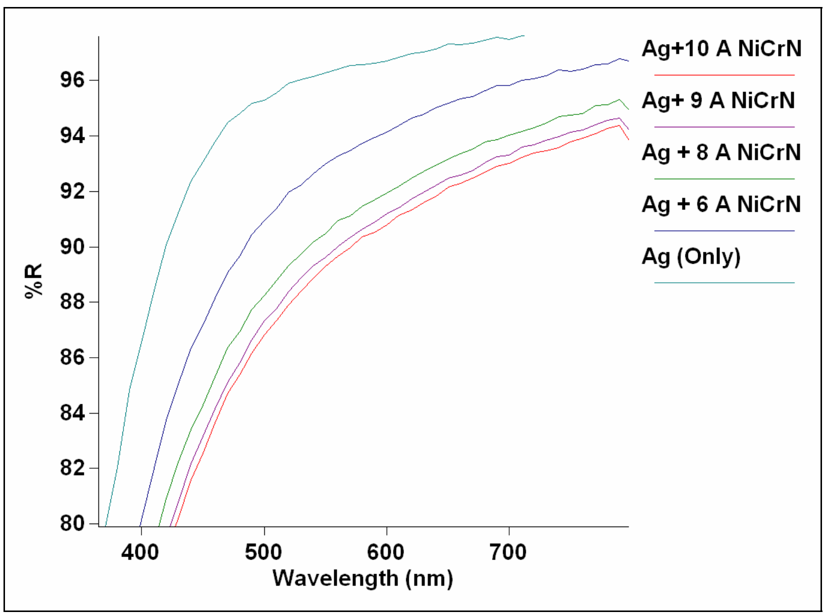

Figure 2: Reflectivity of bare silver and silver coated with Ni-CrNx clusters of varying effective thickness (effective thickness is given in angstroms).

L-Oxide	Reflection Enhancement
H-Oxide	
L-Oxide	
H-Oxide	
L-Oxide	
Si_3N_4	Protected Ag
Ni-CrN_x	
Ag	
Ni-CrN_x	
Mirror Surface	

Figure 3: Protected Ag Design Enhanced with 5-layer Interference Coating.

We found a strong correlation between the Ni-CrNx thickness and the coating durability upon exposure to humidity and thermal cycling. In general, a thicker Ni-CrNx layer produced a more durable silver coating, but at the expense of lower reflectance. This observation supports the conclusions of Chu, et al[4]. Since reflectance degradation of the silver coating prior to launch could be catastrophic to the Kepler mission, the protective nitride layers were applied generously at the expense of some reflectivity. Figure 4 shows the reflectance of the protected silver coating after a five-layer interference coating was applied to enhance the blue spectral region. Figure 4 also shows that no significant change in reflectivity was observed for this coating before and after, both humidity exposure and thermal cycling.

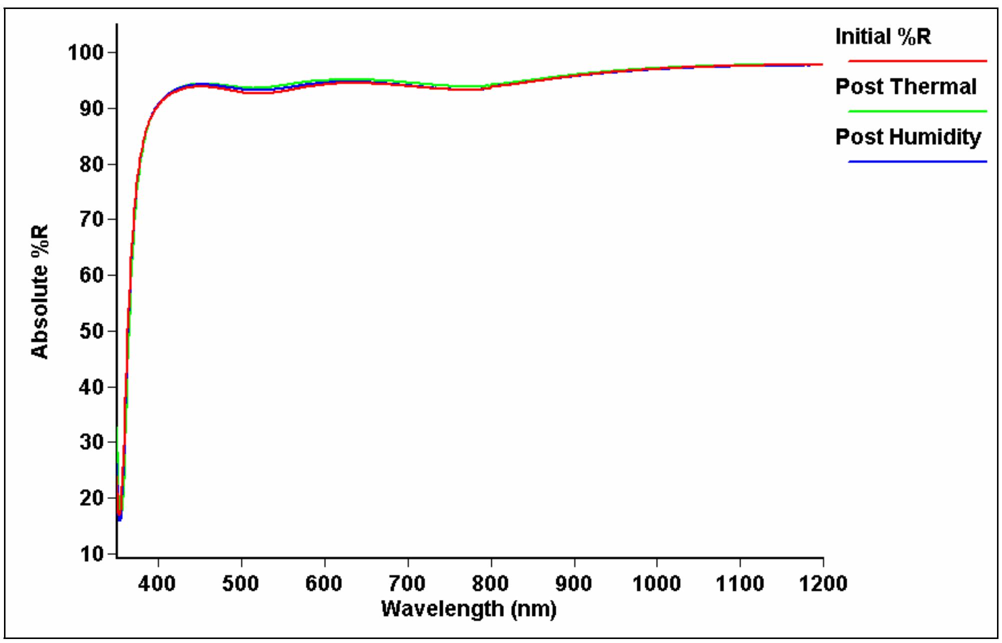

Figure 4: Protected Ag Coating with Five-Layer HL Interference Coating.

3. HUMIDITY, THERMAL CYCLING

The humidity test consisted of a 24-hour exposure at 50°C and 95% RH. The coating was also thermal cycled 30 times from -80°C to +35°C and the reflectance was measured before and after each exposure test. Following environmental exposures, the coating passed MIL-13508C adhesion and moderate abrasion tests.

4. SPACE RADIATION EXPOSURE TEST

The Kepler Space Telescope will be placed in a trailing earth orbit. While the telescope structure provides considerable shielding of the primary mirror, a small fluence of high-energy particles is expected to irradiate the coated surface.

Many dielectric coating materials darken in a space radiation environment. This is primarily due to molecular damage, in the form of dislocated electrons, which leads to light absorption in a process known as color center formation. Molecules with missing electrons may share electrons with metal impurities trapped in the film matrix. It is this sharing of electrons that results in light absorption[7,8,9].

SOC created a dielectric interference coating which is optically stable in space radiation by: (1) minimizing the total thickness of dielectric enhancement layers, (2) manufacturing high purity metal-oxides to minimize the formation of color centers, (3) by using ion assisted deposition (IAD) to create dense coatings that absorb minimal atmospheric moisture.

SOC's 9-layer silver coating was exposed to proton and electron doses, with the estimated energy distributions expected for the Kepler mission. No measurable loss in reflectance was observed. The radiation test was conducted at NASA's Goddard Space Flight Center.

5. COATING UNIFORMITY

Glass microscope slides were positioned on a curved surface that mimicked the prescription of the Kepler primary mirror. The slides were placed at 10 radial positions and the total coating thickness was determined by step measurement using a stylus profilometer. The coating thickness data from the three test runs was averaged and plotted as a function of radial position. The total coating thickness error was found to be less than 30-nm PTV over the 1.4-m clear aperture. Figure 5 is a plot of the averaged data from the three runs.

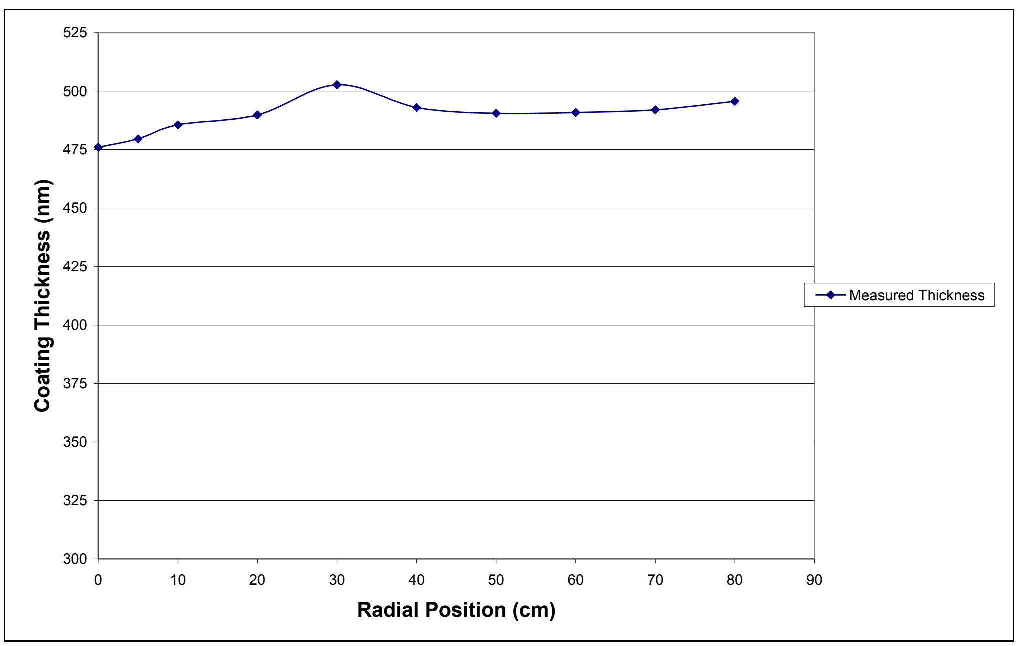

Figure 5: Coating Thickness vs. Radial Position.

6. CONCLUSIONS

A protected silver coating was developed for the Kepler Space Telescope primary mirror, based on an ion-assisted evaporation process. The coating met the durability, uniformity and optical performance requirements of the Kepler mission. The protected silver coating technology invented at LLNL over a decade ago has now been space-qualified and applied to a large primary mirror.

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