Surface Treatment Regimes for Solar Scatter Control in Millimeter Wave Telescope Panels

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Abstract: State of the art millimeter wave telescope panels require surface treatment to control reflective solar radiation scattering. Here we compare different treatment regimes using metrology, simulation, and experimentation to identify optimal processes. © 2021 The Author(s)

1. Introduction

Millimeter wave telescopes are instruments designed to collect astronomical radiation with wavelengths on the scale of millimeters for the purpose of observational studies. Oftentimes simply referred to as radio telescopes, they are typically Cassegrain in style with a large primary reflector followed by a secondary reflector, each with surfaces composed of aluminum panels patterned together to form the complete parabolic or freeform shape [1].

Many radio telescope designs will incorporate a surface treatment for the reflective aluminum panels that make up the primary and secondary mirrors. One example is ALMA (Atacama Large Millimeter/submillimeter Array), which has telescopes that incorporated chemical etching and rhodium plating treatments on their panels [2]. These types of surface treatments serve a variety of purposes, with a primary goal being to control the surface roughness. Surface roughness is a parameter that can play an important role in controlling the temperature gradients of the components that make up the dish and its mechanical structure. Extreme temperature fluctuations have unwanted effects on the performance of the radio telescope due to the creation of thermally induced mechanical distortions on the secondary reflector surface shape [3], and/or potentially on the cryogenically cooled receiver system. The primary source of these temperature fluctuations is the sun itself, due to the large amount of radiance it produces and the fluctuating irradiance levels it imparts on the telescope as environmental conditions change. The surface roughness parameter affects how diffuse or specular the panel surface is for incident solar radiation, which will determine the intensity of the radiation that is scattered onto other components such as the secondary reflector. If the surface roughness of a panel is increased from its baseline state of a few hundred nanometers RMS (Root Mean Square) to the range of a few microns RMS using the appropriately designed surface treatment, the solar radiation will mostly scatter out and away from the dish over a large solid angle upon reflection [2] and minimize any heat energy concentrations or thermal gradients on the telescope components.

This paper will explore the solar scatter effectiveness for different surface treatment regimes applied to millimeter wave telescope panels by incorporating experimental test demonstrations, surface profile metrology, and software simulations. The goal is to identify and outline cost-effective solutions that can be applied to mass panel production.

2. Chemical Etching Process for Millimeter Wave Telescope Panels

One of the surface treatment regimes considered is the process known as chemical etching. We used an alkaline etching process which consists of submerging an aluminum panel in a solution of caustic soda and distilled water. The caustic soda dissolves the aluminum over time, forming sodium aluminate and hydrogen gas. Concentration, time, and solution temperature can be varied to achieve unique surface qualities. We have performed a series of experiments designed to explore these variables and arrive at an optimal etching process that achieves solar diffusivity within the range that meets the requirements for millimeter wave telescope panels, without altering the panel shape. The result of applying this treatment to a small sample panel is shown in Figure 1, where the treatment succeeded in increasing the surface roughness to 1.7 μm RMS.

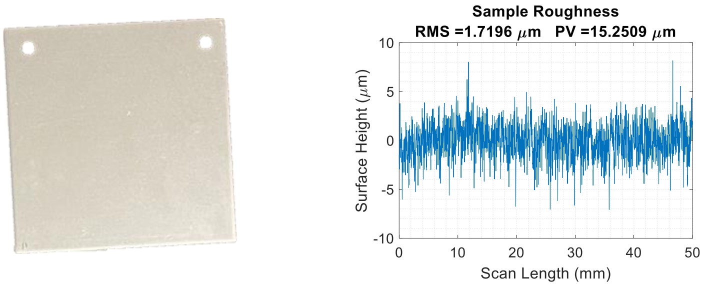

Fig 1. Sample aluminum panel chemically etched with an optimal recipe for solar diffusivity (left); High resolution profilometer scan of the sample showing surface height variation as a function of scan length with RMS and PV (peak to valley) parameters listed (right).

A good parameter to establish the surface quality is its roughness, as it determines the ratio of specular to total reflected radiation by the relation [4]:

$$\frac{R_S}{R_t} = e^{-\left(4\pi\frac{\sigma}{\lambda}\right)^2}, \qquad (1)$$

where Rs is the specular reflectance of the rough surface, Rt is the reflectance of a perfectly smooth surface of the same material, σ is the surface roughness, and λ is the radiation wavelength. For example, the requirement for millimeter wave telescope panels is to achieve at least 98% of specular reflection at the minimum observational wavelength (λ = 1 mm). For this surface treatment regime, the measured surface roughness (σ = 1.7196 μm) will be 99.98% specular for this wavelength, and 0.017% specular at a benchmark wavelength (i.e., $\lambda_{benchmark}$ = 5 μm) in the solar spectrum.

3. Spectral Specular Reflectance Testing Results

Accompanying the process of exploring the different parameters involved in surface treatments such as chemical etching is the process of experimentally measuring the resultant reflection efficiencies of the samples after applying the treatments. This was done to characterize how well wavelengths that fall within the peak solar irradiance range are efficiently scattered. Since solar irradiance peaks in the visible spectrum, an experimental setup was designed using a spectrometer to measure the spectral specular reflectance of samples with different surface treatments over the range of 400 – 1000 nm. Shown in Figure 2 are the results comparing the reflection efficiencies of four chemically etched panel samples that were treated with the same chemical concentration over different lengths of time, as well as an untreated and polished sample for reference. Notably, the results show that the different treatments all succeeded in reducing the reflection efficiency effectively.

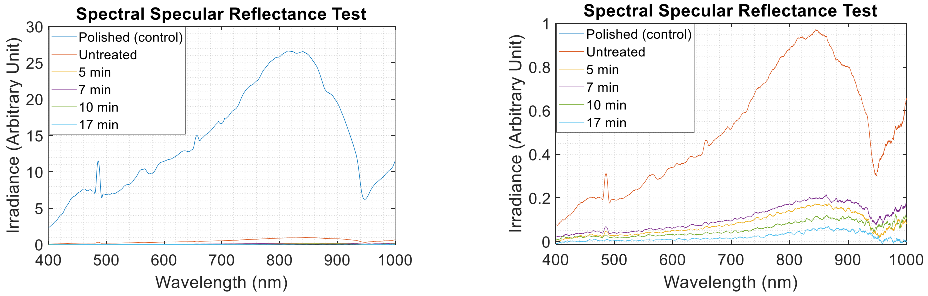

Fig 2. Spectrometer measurement results showing specular reflection efficiency as a function of wavelength for panel samples treated with the same chemical concentration over different lengths of time. The right plot shows a zoomed view of the left with a reduced y-axis limit.

3. References

[1] J. Cheng, "Fundamentals of Radio Telescopes," in The Principles of Astronomical Telescope Design, J. Cheng, Ed. New York, NY: Springer, 2009, pp. 339–376.

[2] J. W. M. Baars, "Reflectivity, scattering and emissivity measurements on samples of prospective ALMA reflector panels," ALMA Memo 566, 2006.

[3] D. Chen, H. Wang, H. Qian, G. Zhang, and S. Shen, "Solar cooker effect test and temperature field simulation of radio telescope subreflector," Applied Thermal Engineering, vol. 109, pp. 147–154, Oct. 2016, doi: 10.1016/j.applthermaleng.2016.08.048.

[4] Bennett, H. and Porteus, J., "Relation between surface roughness and specular reflectance at normal incidence," JOSA 51(2), 123{129 (1961).

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