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Design and fabrication of an albedo insensitive analog sun sensor

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Abstract

A sun sensor is usually included in a satellite for optically measuring the position relative to the sun. The accuracy of a conventional sun sensor is affected by reflected sunlight at the nearby earth atmosphere: the albedo radiation. The part of the spectrum at near IR (1.5 μm) is not included in the albedo radiation, due to the high water absorption in the earth atmosphere. The feasibility of such a near infrared (IR) analog albedo insensitive sun sensor in terms of the design constraints and fabrication is presented. The proposed sensor system comprises a spectral selective coating layer, a black absorbing coating layer, an anti-reflection layer, an InGaAs quadrant detector and is built on a sapphire substrate. The black absorbing ensures that the position measurement is not affected by back-reflected light from the detector surface. A lift-off process is used for patterning of the coating layer.

Keywords: Sun sensor, optical microsystem

1. Introduction

The solar radiation spectrum at sea level has pronounced dips, which are due to absorption in the atmosphere. *Figure 1* shows this spectrum, as compared to the incident spectrum on top of the atmosphere [1]. These dips are also not present in the reflected radiation from the earth atmosphere: the albedo. This is a highly interesting feature to reduce the adverse effect of the earth reflection on the performance of a sun sensor in a nearby satellite.

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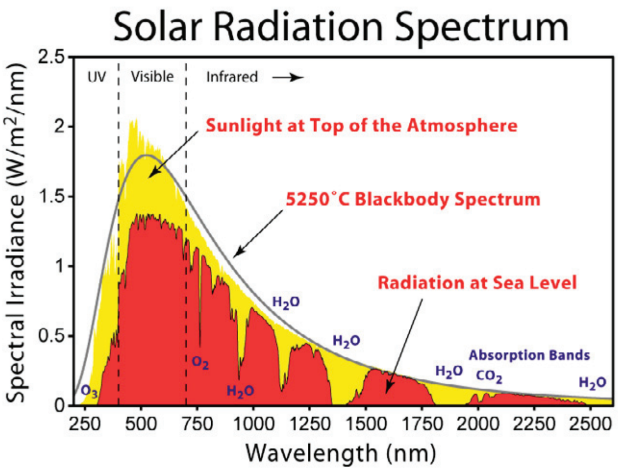


Fig. 1. Solar spectrum at the top of the atmosphere and at sea level [1]

An analog sun sensor measures the position of a satellite relative to the sun by projection of the sunlight through a hole (aperture) in a shield onto a PSD or a 2×2 array of detectors, as shown in *Figure 2*. Digital sun sensors have also been investigated using a full CMOS imager and signal processing to calculate the sun position from the image. The position of the projected light spot depends on the angle of incidence and, hence, on the satellite position relative to the sun. This information is used for directing an antenna or the solar panel or by the internal navigation system for attitude control.

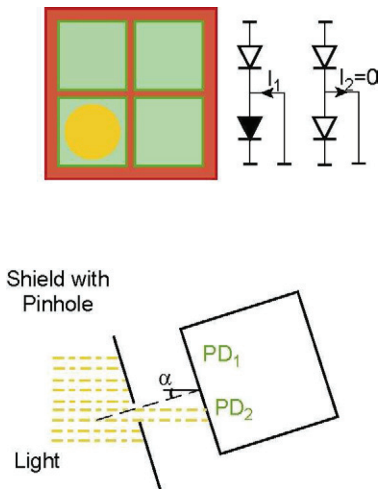


Fig. 2. Operation of the analog sun sensor

There are two sources of light incident on the sun sensor: the intended signal directly from the sun and the stray light reflected from the earth atmosphere. The latter source of radiation is generally referred to as albedo. The albedo in the 1350 nm band is strongly reduced due to the absorption by water molecules in the atmosphere (see *Figure 1*). Therefore, selectively measuring the incident light in that particular band allows the measurement of the satellite position with respect to the sun, not affected by the earth reflection. Of course this principle can also be applied to other absorption bands (e.g. 1850 nm). However, the 1650 nm spectral band conveniently corresponds to the spectral response of an InGaAs photodiode and is selected for this reason

2. Sensor design and fabrication

The sensor includes a sapphire substrate and an InGaAs quadrant detector illustrated in *Figure 3*. The substrate serves as the optical system with an aperture in a black absorbing coating at the topside, a selective coating at the topside with a bandpass and an anti-reflective coating at the bottom side. Experiments are performed with both sapphire and silicon substrates. The InGaAs detector is illuminated with only the light in the selected band and passing through the aperture. Sapphire is used, because of its low refractive index. The black absorbing layer avoids multiple reflections between the detector and the bottom side of the substrate.

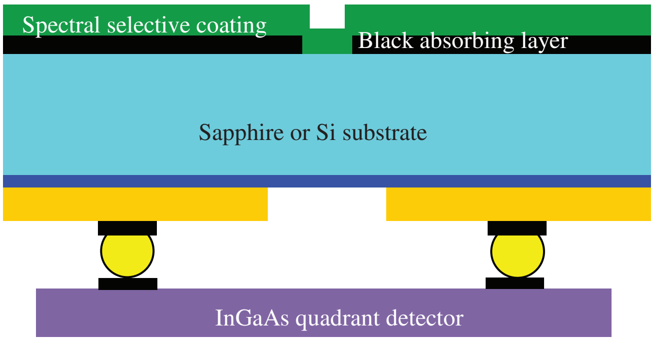
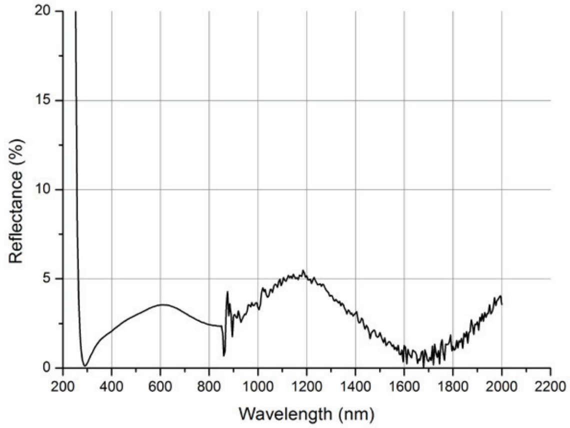


Fig. 3. Schematic diagram of the optical system

3. Experimental Procedure and Results

Figure 4 shows the measured reflectance of the coated layer with a thickness of about 400 nm. The required aperture of the optical window is determined by the size of quadrant detector and the maximum angle of the incident light. A lift-off process is used directly following the deposition of the black coating layer to realize the aperture. Pin-holes that would increase the inaccuracy of system were found in the samples when using ultra-sonic bath during lift-off process as shown in *Figure 5*. The edge roughness of samples is analyzed edge using white light interferometry. *Figure 6* shows the results on the 350×350 μm^2 aperture. The thickness of the layer is around 390 nm with contour peak of about 147 nm. Although techniques for reducing the contour peak are available, the values obtained in this simple process are sufficient to avoid a significant effect of the aperture dimensions on the performance of sensor..



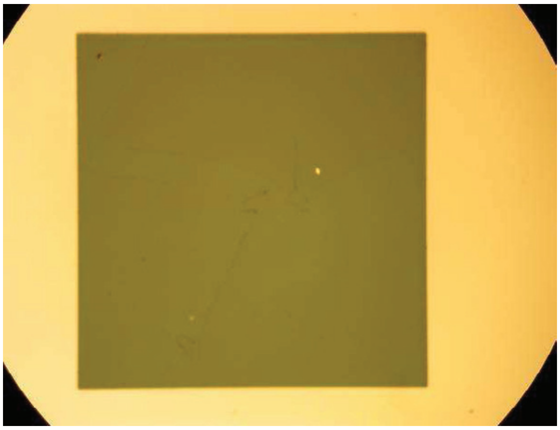


Fig. 4. Measured reflectance of the black coating

Fig. 5. Pinhole formation after lift-off processing.

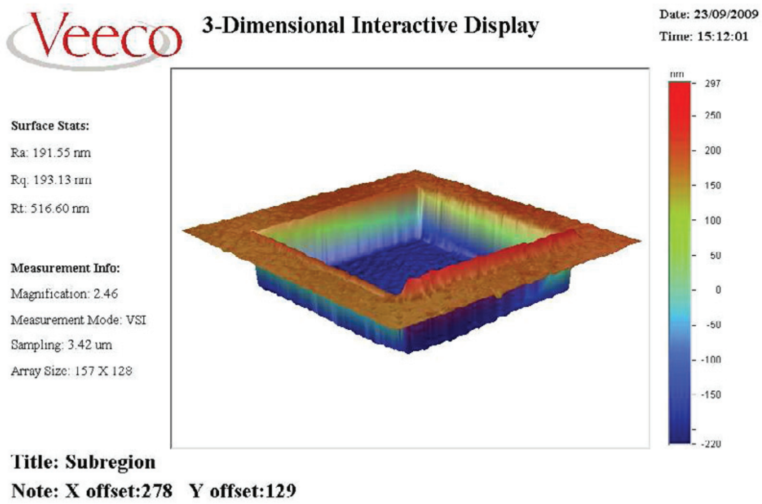


Fig. 6,.*3D Profile of edge roughness of a 350×350 μm² aperture after lift-off.*

4. Conclusions and Future Work

The main problem is the pinhole formation during lift-off. The process in being improved and fabrication of prototypes is scheduled.

References

[1] Data from American Society for Testing and Materials (ASTM) G-173-03 reference spectra.