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High-precision narrow-band optical filters for global observation

Atsuo Kurokawa, Yasuhiro Nakajima, Shinji Kimura, Hiroshi Atake, Showa Optronics Co., Ltd. (Japan)
Yoshihiko Okamura, Kazuhiro Tanaka, Japan Aerospace Exploration Agency (Japan)
Shunji Tsuida, Kenichi Ichida, Takahiro Amano, NEC TOSHIBA Space Systems, Ltd. (Japan)
E-mail:a-kurokawa@soc-ltd.co.jp

ABSTRACT

Earth observation satellites are launched to monitor global and long-term climate change, water circulation, and other phenomena. These observations also help increase the accuracy of predictions of environmental changes. Optical band-pass filters that have narrow transmission bands corresponding to specific radiation wavelengths ranging from the near ultraviolet (UV) to infrared (IR) are used for sensor observations. To improve the measurement precision, the required specifications for observation systems including optical band-pass filters are becoming more stringent. The Second-generation Global Imager (SGLI) on the Global Change Observation Mission-Climate (GCOM-C) is a multiband optical imaging radiometer. The optical band-pass filters used for such imagers must have a highly uniform center wavelength (CWL). This paper examines the relationship between the geometry of the substrate fixture and variations in the film thickness on the substrate. A CWL uniformity of better than 0.1% peak-to-peak (pp) in an area of 100 mm × 1 mm is achieved. In addition, it is shown that the CWL shift due to the telecentric error, or the inclination angle of the chief ray in image space, can be compensated for by controlling a filter's CWL distribution.

Keywords: band-pass filter, narrow transmission band, film thickness, uniformity, telecentric

I. INTRODUCTION

The Global Change Observation Mission (GCOM) is the Japan Aerospace Exploration Agency's next Earth environmental observation mission; it consists of the GCOM-W and GCOM-C satellites series for monitoring carbon, water cycles, and climate change [1]. The GCOM-W1 that was launched in May 2012 carries the Advanced Microwave Scanning Radiometer 2, a microwave sensor; it is not discussed in detail here. The GCOM-C1 will carry the Second-generation Global Imager (SGLI) [2, 3], an optical sensor in the wavelength range from the near ultraviolet (UV) to thermal infrared (TIR).

The components of the SGLI are listed in Table 1. The SGLI Visible and Near Infrared Radiometer (VNR) has the important mission of observing land aerosols, vegetation biomass, and other targets with high accuracy to improve sub-processes in numerical climate models. For this reason, high precision of the band-pass filters used for the line sensors is demanded.

Table 2 lists the main specifications of the SGLI-VN filters, which should be fulfilled over an effective area of 82 mm × 1 mm on a substrate. These types of filters are usually realized by optical coatings and designed as interference filters with a dielectric multilayer.

The signal-to-noise ratio can be increased by optimizing each transmission bandwidth, which would make SGLI-VN capable of more precise measurement. This requires both a high central wavelength (CWL) precision and high relative CWL uniformity over the entire effective area of the substrate.

This paper mainly discusses the issues in manufacturing VN filters to meet these demanding specifications and how to fabricate them with simpler methods.

Table 1 Components of SGLI

	Sensors		Monitoring range	Polarization
SGLI	VNR	VN: Visible&Near infrared	380.0-868.5 nm	Unpolarized
		P: Polarimetry	673.5-868.5 nm	P-polarized
	IRS	SW: Shortwave infrared	1050-2210 nm	Unpolarized
		T: Thermal infrared	10.8-12.0 μm	Unpolarized

II. STRUCTURE OF SGLI-VN FILTER MODULE

The VN filter module is being developed for highly precise observations. Therefore, it is very important not only to realize the specifications in Table 2 but also to suppress stray light in the optical system to low levels, i.e., less than 0.3% of the observation light intensity. However, multiple reflections caused by the surface reflection of lenses, VN filters, and line CCD sensors cause stray light to appear and degrade the observation precisions. In particular, VN filters have enormously high reflectance because they are fabricated using multilayer thin film coatings that reflect unwanted light instead of absorbing it.

To reduce stray light, it is extremely effective to incline the VN filters by 10° or more to the plane normal to the chief ray so that the inner wall of the chassis absorbs the reflected light from each element. However, because the VN filters are intended for the observation of unpolarized light, their polarization sensitivity must be less than 0.5%. Calculations revealed that the maximum inclination of the VN filters is 4°.

For these reasons, the stop band function for each VN filter is provided by V filters and F filters, which reject the light relatively close to and far from the passband region, respectively. In addition, colored glass filters are used as substrates for almost every filter to cut the shorter wavelength range. For example, the spectral characteristics of the V9, F5, and VN9 filters are shown in Fig. 1.

Table 2 Main specifications for passband characteristics of SGLI-VN filters

		unit	VN1	VN2	VN3	VN4	VN5	VN6	VN7	VN8	VN9	VN10	VN11
Center Wavelength (CWL)	Nominal value	nm	380.0	412.0	443.0	490.0	530.0	565.0	673.5	673.5	763.0	868.5	868.5
	Tolerance	nm	±1.5	±1.6	±0.9	±1.0	±1.1	±2.3	±1.3	±1.3	±1.5	±1.7	±1.7
		%	±0.4	±0.4	±0.2	±0.2	±0.2	±0.4	±0.2	±0.2	±0.2	±0.2	±0.2
	Uniformity	nmPP	0.7	0.7	1.1	1.2	1.3	1.0	1.6	1.6	1.4	2.1	2.1
		%PP	0.18	0.18	0.24	0.24	0.24	0.18	0.24	0.24	0.18	0.24	0.24
Band width	FWHM	nm	10	10	10	10	20	20	20	20	12	20	20
	Tolerance	nm	±1.0	±1.0	±1.0	±1.0	±2.0	±2.0	±2.0	±2.0	±1.0	±2.0	±2.0

※Stop-band range is 300–1100 nm.