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Narrow Pass-Band Optical Filters for Space-Borne Remote Sensing Applications

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Abstract

Optical characterisation of 532 nm, 200 pm passband and 1064 nm, 1 nm passband IAD filters after exposure to proton irradiation, temperature cycling and angle tuning.

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In laser-based remote sensing at optical frequencies daylight can prove problematic, introducing noise which may saturate the detection system. The use of a simple neutral density filter, while reducing the effects of the background optical radiation will also reduce the detected signal strength. To compensate by increasing the output power of the laser is expensive in both cost and power for satellite based systems. A much simpler solution is to spectrally filter the frequencies that enter the optical system. In the Geoscience Laser Altimeter System, GLAS[1], this will be accomplished with an etalon and interference filter[2] combination. The etalon has a passband of ~25 pm and a free spectral range of 300 pm. The interference filter must pass the central etalon band while blocking adjacent modes. This can be achieved using a commercially available Ion-beam-Assisted Deposition, IAD, filter of ~200 pm FWHM. A further critical constraint is that the filter pass-band remain centered on the laser to within a few tens of picometers and be impervious to the effects of radiation, temperature and moisture, (long term extreme drying).[3] In this paper, we report on the characterisation of the narrow pass-band filter of nominally 200 pm and 1 nm FWHM centered at 532.2 nm and 1064 nm, to the effects of ionizing radiation, temperature and incident angle.

To characterize the narrow pass-band filter to better than 20 pm we use a Fabry-Perot scanning etalon and a green LED as a high resolution spectrometer. A schematic of the setup is shown in Figure 1 and described here. A broad-band source, a green LED with essentially constant intensity over the range of interest (532 nm-533 nm) fiber-coupled to the bread board, is collimated with a 1:1 telescope and illuminates the Filter Under Test (FUT) collinear with a frequency doubled-cw Nd:YAG and a frequency doubled Q-switched Nd:YAG. Both lasers' wavelengths were continuously monitored using a Burleigh Wavemeter WA1500 and a Burleigh Pulsed Wavemeter giving typically ± 3pm accuracy and providing wavelength calibration. All beams were spatially filtered, collimated and apertured to produce a beam of uniform intensity over a region of nominally 30 mm diameter.

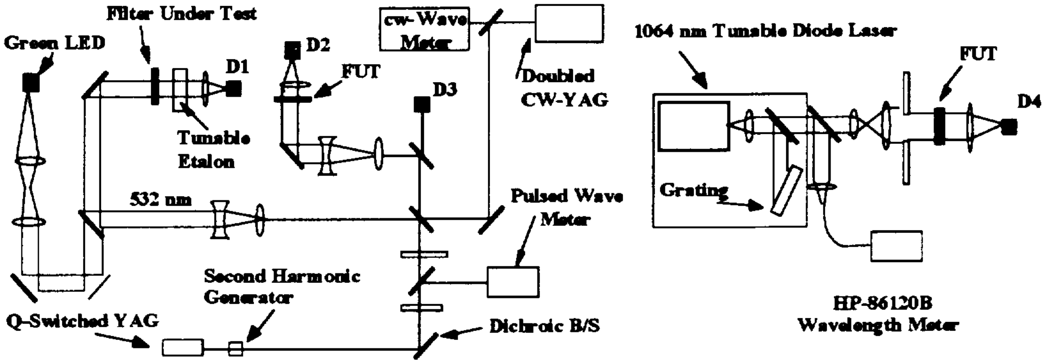

Figure 1. Schematic of the experimental setup showing both the 532 nm and 1064 nm apparatus.

Great care was taken to ensure that the filters were aligned perpendicular to the incident beam The light transmitted by the FUT was then analysed with a Queen's Gate Model ET50FS-1010 scanning Fabry-Perot etalon with a finesse of 28 and a Free Spectral Range of 600 pm. This gives a device with the ability to monitor shifts in wavelength of the order of a few picometers. The transmitted light from the etalon was focused on to a silicon APD, D1, and the detected signal recorded as a function of the Fabry-Perot's cavity-length using a Macintosh-pc, running LabView, over a GPIB via an HP Digitizing Oscilloscope. The magnitude of the peak transmission of the filter was then determined from a second transmission measurement. The FUT was placed in front of detector D2 and the signal ratioed with the incident intensity measured on D3. Integrating spheres attached to D2 and D3 were used to reduce the sensitivity to minor variations in alignment. Care was taken to ensure that background, aperture effects and incident angle were all controlled.

The 1064 nm filters' transmissions were measured using the set-up shown in Figure 1 (with better than 10 pm resolution). Optical feedback from an external bulk grating and temperature were used to tune the wavelength of a 1064 nm diode laser through the passband of the FUT. The laser wavelength was monitored using an HP 86120 B wavelength meter. The spatially filtered collimated, 21.6 mm beam was aligned to pass through the center of the filter at normal incidence. For each wavelength, the incident power was compared with the transmitted power.

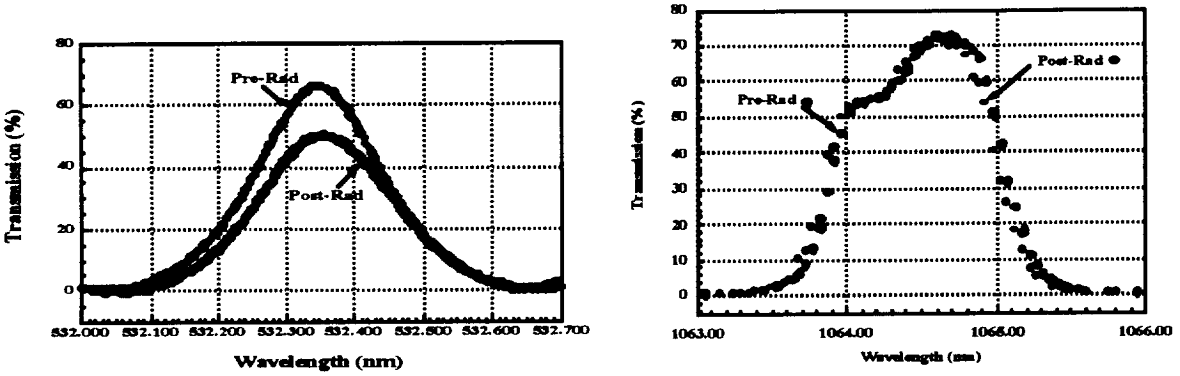

Figure 2 Typical transmission spectra for the 532 and 1064 narrow pass filters before and after 30 KRads of irradiation with 123MeV protons.

Baseline spectra were taken for all filters. Typical transmission curves are shown in figure 2. The results are summarised in Table 1. To simulate exposure to three years in orbit the filters were irradiated with high-energy protons at the Indiana University Cyclotron Facility, IUCF [4]. The accumulated dose in orbit over three years of exposure to ionising radiation is expected to be ~30 KRads. The expected median kinetic energy of protons in this orbit is ~123 MeV. The cyclotron was set to produce 123 MeV protons in a flux of ~10 Rad/s with a fluence of $3.8\text{x}10^{11}\text{cm}^{-2}$. The filters, one at a time, were carefully positioned to sample only the central portion of the proton beam ensuring uniform exposure over the filter. The filters were then irradiated to an accumulated dose of 30 KRads, two filters were taken to twice the expected maximum value, 60 KRads †, two filters were used as controls and not irradiated. The activated filters were allowed to decay (48 hours) and returned to NASA-GSFC for additional characterisation.

Filter 532nm	Peak - λ ±0.006 nm (pre)	Pre-Rad Transmission	BandWidth (pm)	Peak - λ ±0.006 nm (post)	Post-Irradiation Transmission	BandWidth (pm)
† 1.1	532.306	87.6%	227	532.305	67.7%	225
2.1	532.298	51.2%	263	532.2975	42.5%	258
N1	532.375	59.9%	198	532.374	58.1%	194
N2	532.265	45%	208	532.267	37.8%	206
† N3	532.345	66.5%	211	532.355	50.7%	229
N4 C	532.351	64.8%	217	532.353	65.7%	220
#4 C	1064.8	75%	1 nm	1064.8	75%	1 nm
#16	1064.6	74%	1 nm	1064.6	74%	1 nm
#17	1064.55	72%	1 nm	1064.55	72%	1 nm

Table 1. Pre and post radiation data. The control filters are denoted with a C

The bandpass and peak transmission of all filter's remained the same to within the accuracy of the experiment. Only the overall transmission of the 532 nm filters decreased. In operation, due to a greatly reduced natural flux, the radiation induced defects responsible for the increase in absorption will be generated over a longer timescale and self-annealing of the defects will tend to ameliorate the degradation and this decrease is the expected "worst case". Continued transmission measurements will enable an accurate decay constant for these defects to be determined and thus better predict the performance of the filter over the lifetime of the mission. The post-irradiation results are also summarized in Table 1.

The filters are manufactured such that their passband is slightly longer than that desired and is angle tuned to shorter wavelengths in operation. This necessitates great care be taken to ensure that pre- and post-radiation tests were conducted with the filters normal to the incident beam. The angle tuning of the filter was also measured.

Figure 3. Plot of the peak-transmission as a function of incident angle.

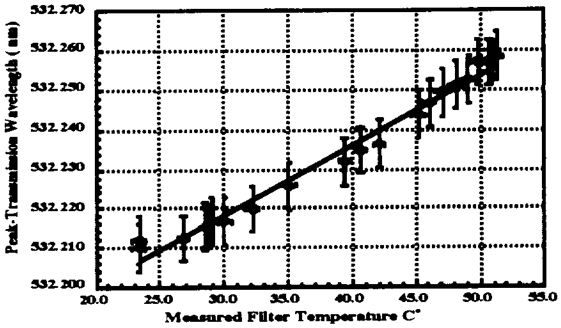

Figure 4. Temperature tuning of the 532 nm Barr Filter..

The FUT was placed in a single-axis gimbal mount positioned in front of the etalon and tuned through a range of ±5° from normal. The filter was illuminated with the broadband LED source and Q-switched laser. The filter was then tilted and the transmission as a function of angle and wavelength recorded The results are plotted in figure 3. The filters can be angle-tuned ~600 pm shorter in wavelength without significant loss of transmission or bandpass distortion.

In orbit, during normal operation, the temperature of the filter is expected to change a few degrees C depending on several extraneous factors, so it is important to note the temperature tuning of the filter. The filters were placed in an enclosure and aligned normal to the incident beam and the throughput analysed with the scanning etalon as a function of temperature. The filter was found to tune to longer wavelengths at ~1.8 pm/C°, see figure 4.

In conclusion the Barr filters[1] were subjected to irradiation simulating 3 years of space flight, temperature cycling and angle tuning and from precision optical measurements all remained stable. Only the 532nm filters suffered decreased transmission after proton irradiation.

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