Development of extreme narrow band filter for LGS daytime use

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Introduction

The use of laser guide star (LGS) in daytime expands the operational time of telescope for AO instruments, especially for thermal infrared wavelengths, because the sky brightness is not so different from night to daytime. However, the daytime sky background at 589nm is about 10^6 times brighter than a bright night. However, as the bandwidth of sodium D2 line is a few GHz, an extremely narrow bandpass filter at this wavelength makes it possible to use LGSs during the day.

Begin with developing an interference filter, we found that the spectral bandwidth could not be achieved at the level of 1nm. Then we started to investigate etalon technology to achieve an extremely narrow band filter. We focused on two different technologies, one is an air-gap etalon and another is a thin etalon layer sandwiched by the high reflective coating. We present the prototype fabrication of etalons based on both technologies and report the results of measurement of the peak transmission and spectral bandwidth.

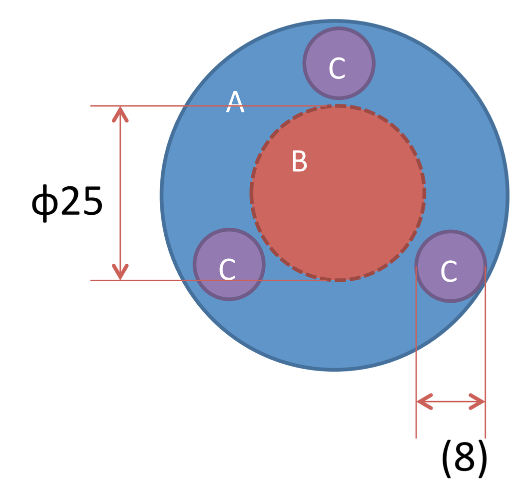
Top-level specification of NBP filter

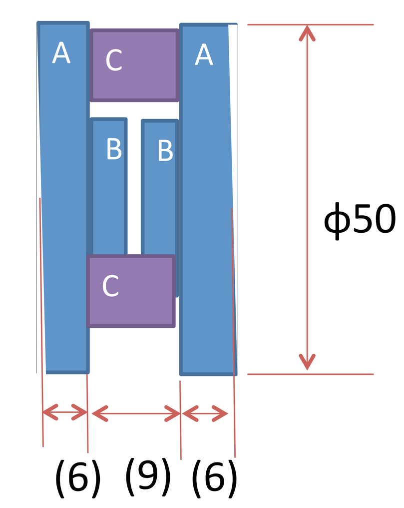
PARAMETER	VALUE and TOLERANCE	TOLERANCE NOTES
General		
Operating/Working Temperature	0° C ± 10° C	***"Operating Temperature"***
Central Wavelength	589.16 nm	***"Operating Wavelength"***
Optical Design		
Surface shape	plano-plano	
Working aperture (all FOV)	30 mm	clear aperture
Angle of incidence	0 +- 1deg	
Surface Quality		
Surface quality	60/40	scratch and dig
Transmitted wavefront	λ/10 RMS @ 632nm	over clear aperture prior to coating
Optical Coating		
Central Wavelength	589.16 nm	at operating temp
Transmitted Bandpass	FWHM < 0.3nm	at operating temp
Peak transmission	T > 50% at 589.16 nm	
Out of bounds transmissivity	> OD6 from 400 to 1100nm	at operating temp
Substrate Properties		
Substrate Material	-	At discretion of vendor
Optic shape	Circular	
Optic size	35.0 mm diameter +0.00/-0.1mm	See Note 1
Optic thickness	<8 mm±0.25mm	See Note 1
Bevel	0.3mm x 45 deg	Standard bevel
Miscellaneous		
Quantity	1-2	no spare

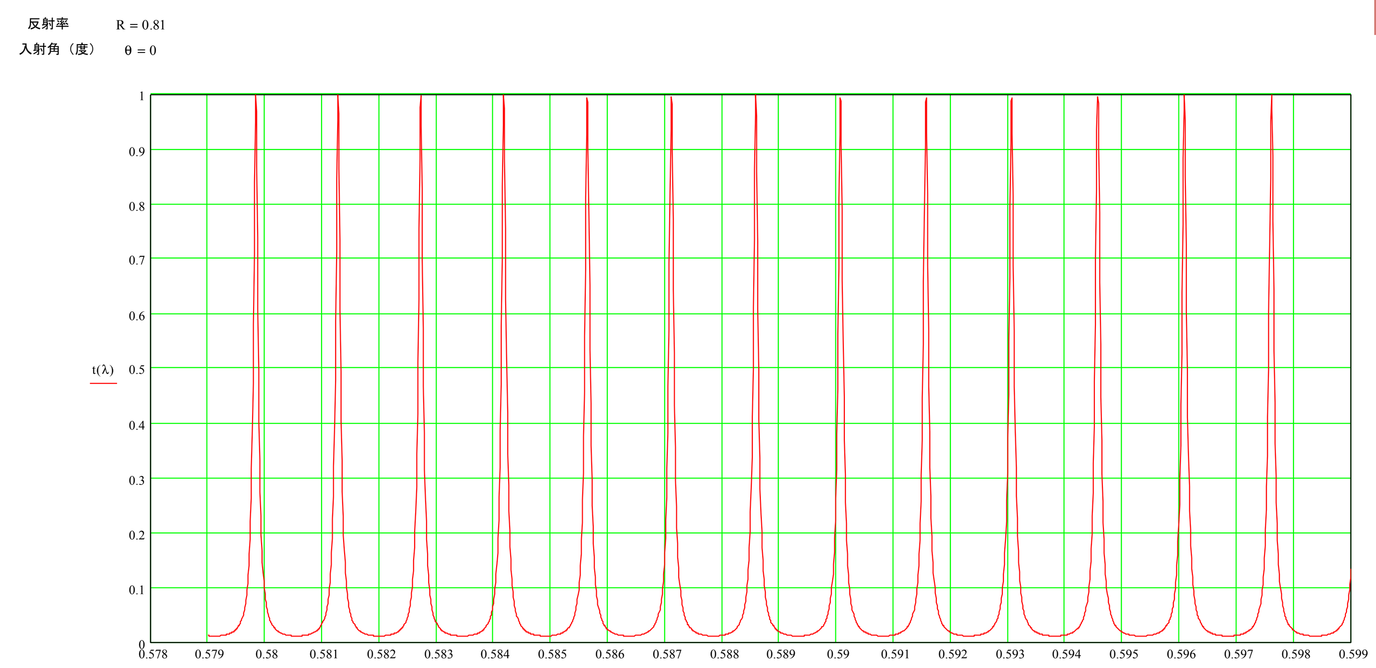
Air-gapped etalon filter

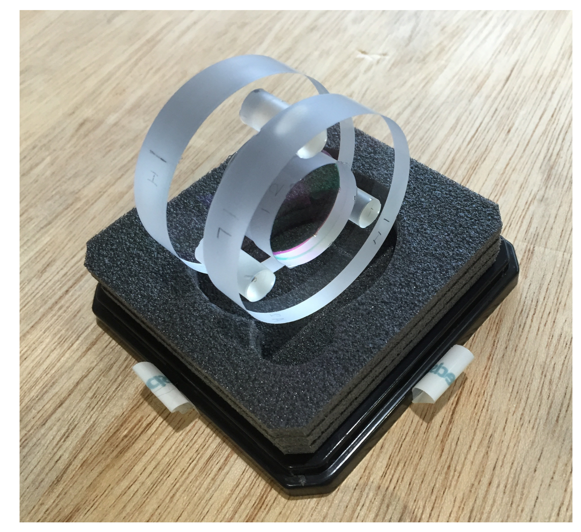
The table below shows a parameters of air-gapped etalon. The bandpass range can be achieved 0.1nm FWHM, though, transmission at wavelength other than sodium D2 line is higher than our specification. Therefore, we have to add another bandpass filter, whose bandpass width is around 1 or 2 nm. But this is not a critical challenge to achieve.

Parameter	Value
Reflectivity of etalon	81%
Finesse	15
Free spectrum range	1.5 nm
Bandpass width	0.1 nm
Air gap	115.3 micron



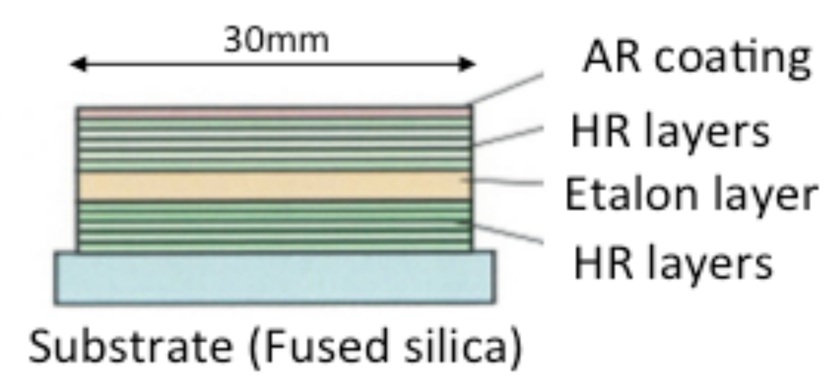




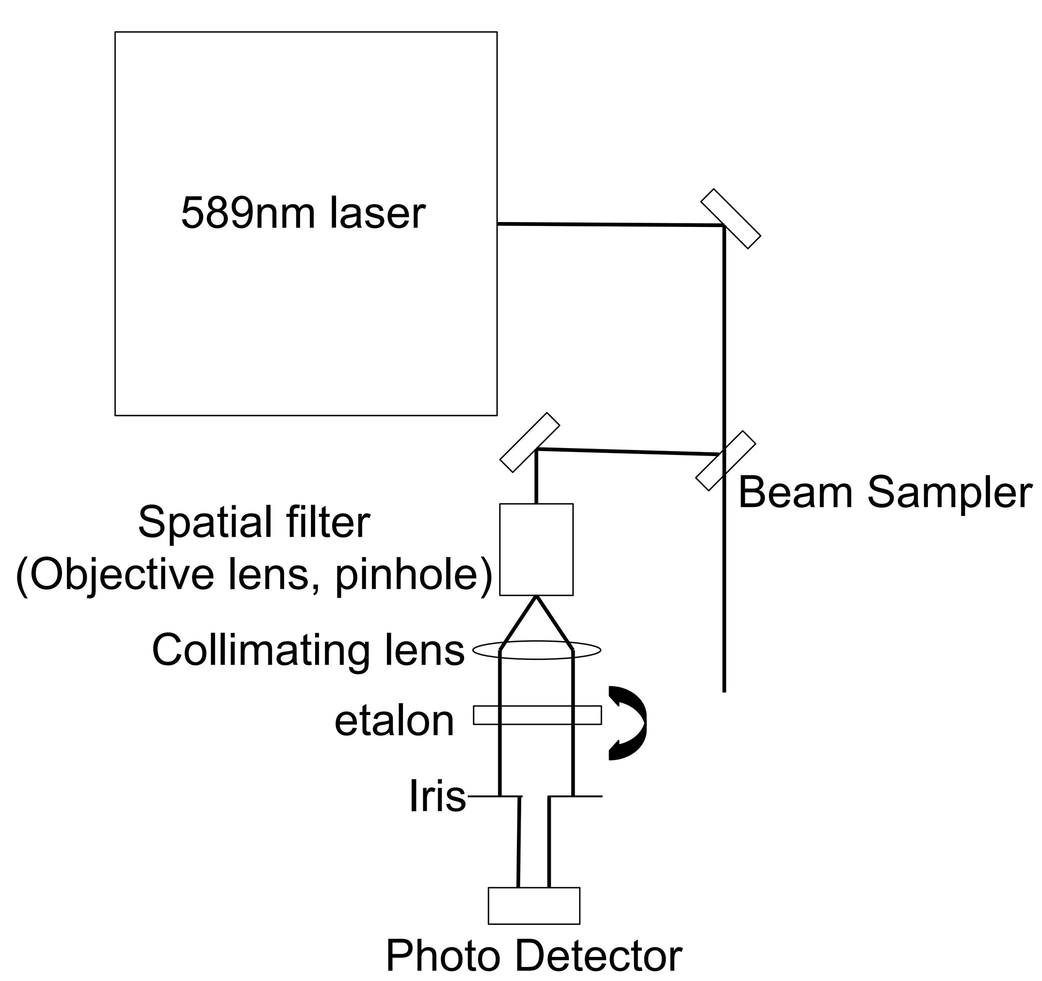


Multi-layered etalon filter

The second candidate of etalon filter is designed by using multi-layer coating technology. As you see in the figure left below, we develop several types of multi-layers on the substrate, made by fused silica. The layer in the middle is sandwiched by high reflective layers, which act as a etalon. The thickness of middle layer is designed from 1 to 4 micron. The total throughput can be tuned by the reflectivity of HR layers. It is difficult to control the exact thickness of middle layer so that the central wavelength of etalon filter is slightly longer than sodium D2 line. Thus we tune the central wavelength by tilting the etalon unit. According to the model calculation, we can tune about 3nm by tilting the etalon by 8 degrees.



Characteristics of etalon filter



The experimental setup is shown on the left figure. The laser beam at the wavelength of 589nm is fed into the spatial filter and collimated by the lens. etalon filter is mounted on the rotational stage to adjust the incident angle of the laser collimated beam. The peak transmission of air-gap etalon reached around 80%, the spectral bandwidth is approximately 0.1nm and the free spectral range (FSR) is about 1.5 nm, which are matched with the design specification. The next challenge of air-gap etalon is how to block the adjacent spectral transmission. For the thin etalons with high-reflective coating, the peak transmission is distributed around 40% to 70%, the spectral bandwidth is about 0.15nm to 0.6nm. Thus, the designed specification and the measurement results have been not exactly matched, but we found some empirical relationship between these performance parameters. Also the central transmission wavelength varies across the etalon aperture. Finally, we propose the second
prototype fabrication of thin etalon sandwiched by high reflective coating, including the experience and results of first prototype fabrication.