New Concept of a Highly Efficient High Resolution Spectro-Polarimeter

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Abstract

Volume Phase Holographic gratings (VPHG)[1][2][3][4][5] operating at 90° total internal diffraction angle are perfect polarizing beam splitters and efficient dispersers. A concept is shown that exploits this for a 3 channel, very highly efficient spectro-polarimeter with high spectral dispersion. The concept could be used for a wide variety of scientific application on TMT ranging from studies of very high redshift galaxies/clusters, nebular spectroscopy, ISM, stellar astrophysics, and exo-planet spectro-polarimetry at up to 10^6 spectral resolution.

Technical Description

A VPHG with an internal incidence angle of 45° can be a perfect polarizing beam splitter[2][5][6] or holographic polarization-separation device (HPS).[6]

They are commonly used as filters for laser applications (Kaiser Optical Systems, Inc. – Holographic Laser Bandpass Filters, HLBF[7]). (http://www.kosi.com/Holographic_Filters/laserbandpassfilters.php)

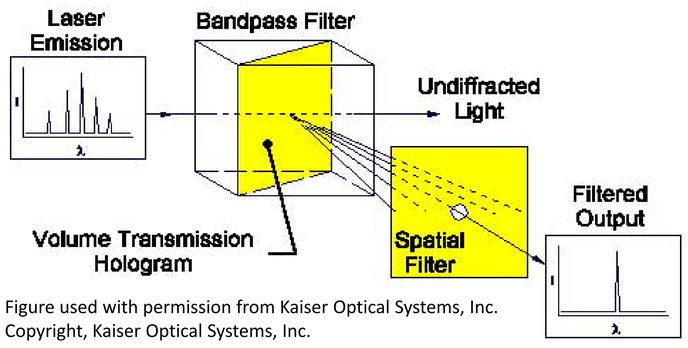


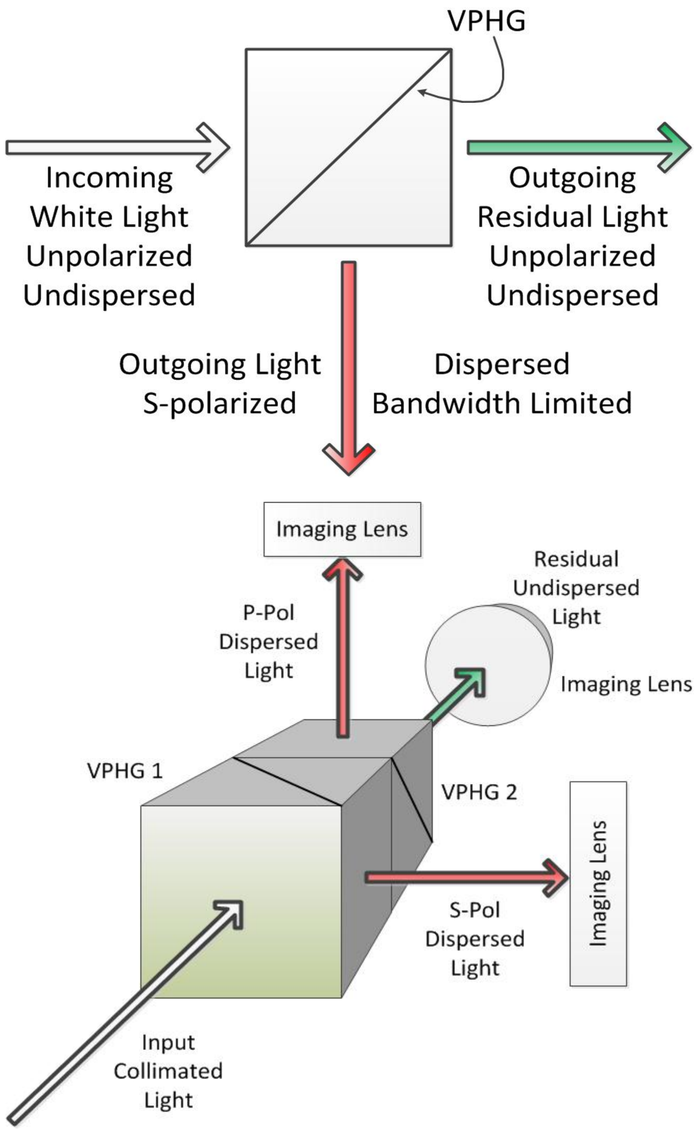
Figure used with permission from Kaiser Optical Systems, Inc.

The concept presented here utilizes two such HPS devices (without spatial filters) with the second rotated 90° to the first to diffract the orthogonal polarization state. A nearly white light image passes straight through. Three channels are produced:

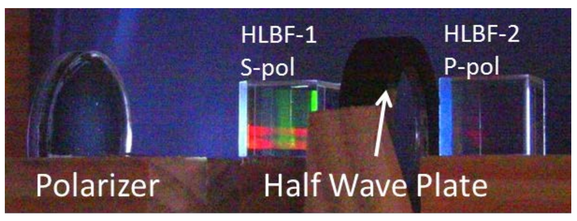
s-polarized dispersed light
p-polarized dispersed light
undispersed white light

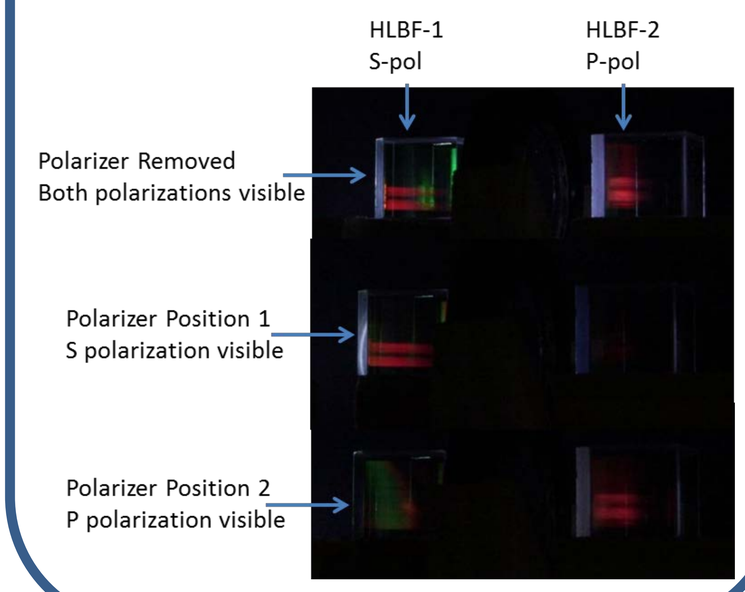
A half-wave plate can be located between the two beam splitters to allow rotation of the second splitter for alternative spatial orientations (as demonstrated at the right side of this poster).

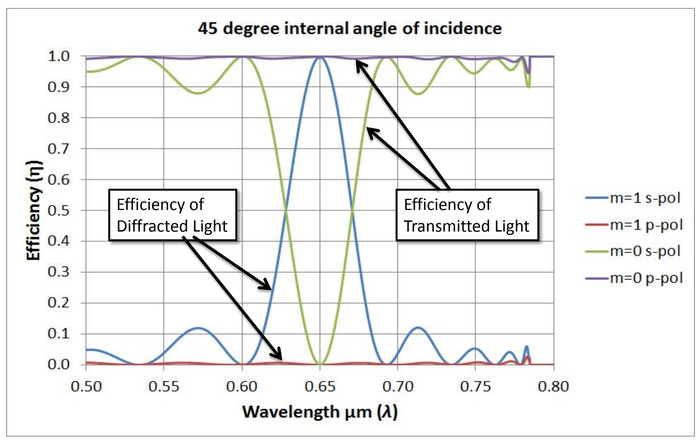
Additional beam splitters and/or gratings can be used in series for the same polarization state to better filter out any residual unwanted polarization and to increase or decrease the spectral dispersion (see double grating concept below).



Demonstration of concept with two sample HLBFs from Kaiser Optical Systems, Inc.
- ~15 mm clear aperture
- Design wavelength unknown, but near-IR
- Half Wave Plate used to rotate P polarization







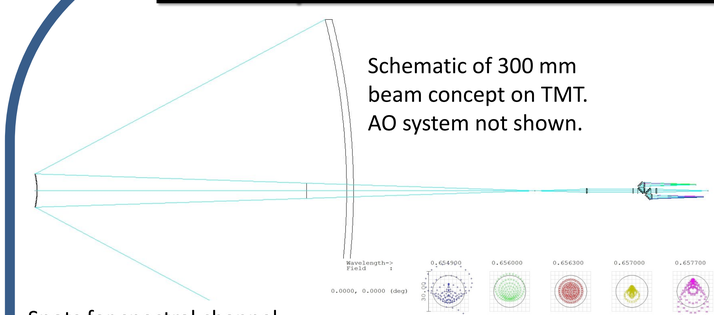
RCWA modeled efficiency (diffracted and transmitted) curves for a notional 3263 l/mm grating at 650 nm. The surface and material losses are not included. AR coatings could be optimized to very high efficiencies given the narrow spectral bandwidth.

Estimated Telescope plus Instrument Efficiency

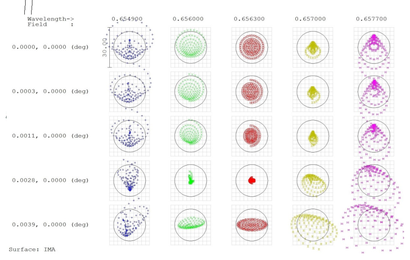
Component	*S-Pol*	*P-Pol*	*Imaging*
Primary Mirror	0.98	0.98	0.98
Secondary Mirror	0.98	0.98	0.98
Corrector Lens	0.97	0.97	0.97
Collimator	0.97	0.97	0.97
Waveplate Analyzers	0.97	0.97	0.97
Filter	0.90	0.90	0.90
VPHG-1	0.92	0.95	0.05
Half Wave Plate		0.97	0.97
VPHG-2		0.92	0.97
Optional Fold Mirror	0.98	0.98	
Camera Lens	0.97	0.97	0.97
Detector	0.90	0.90	0.90
Per Channel Total	0.62	0.58	0.032
Total Fraction Photons Detected	0.31	0.29	0.032

Total Combined Efficiency 63.2%

Concept for a Diffraction Limited 30m Telescope



Schematic of 300 mm beam concept on TMT. AO system not shown.



Spots for spectral channel with 300 mm beam diam. Boxes are 2 pixels (30 µm). Lenses are identical doublets.

Parameter	Value
Beam Size	300 mm [100 mm] diameter
Camera f/#	15.0
Detector Format	4096 x 4096 pixels
Pixel Size	15 x 15 microns
Spectral Coverage	654.9-657.7 nm (28 Å) [652.0-660.6 nm (86 Å)]
Spectral Dispersion	0.007 [.021] Å/pixel
Spectral Resolution	469,000 [154,000] λ/Δλ (2 pixel)
Spatial Field Coverage	28 arc-seconds
Spatial Sampling	0.007 arc-sec/pixel

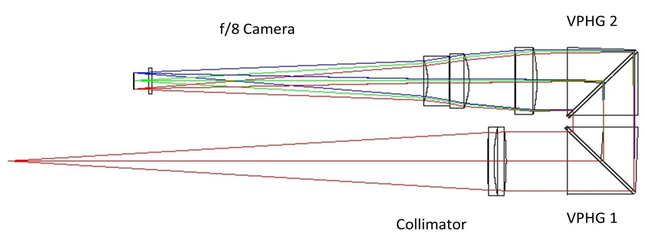
Schematic of 300 mm beam concept.

Parameters for Seeing Limited

Parameter	Value
Beam Size	300 mm diameter
Camera f/#	2.0
Detector Format	2048 x 2048 pixels
Pixel Size	15 x 15 microns
Spectral Coverage	651.3-661.3 nm (100 Å)
Spectral Dispersion	0.053 Å/pixel
Spectral Resolution	8850 λ/Δλ (14 pixel = 0.2" slit)
Spatial Sampling	0.014 arc-sec/pixel

This concept does not compete with existing TMT concepts for seeing limited high resolution due to limits on prism size.

Double Grating Concept



Doubles the dispersion/resolution.

300 mm beam diffraction limited concept could achieve R~1,000,000 with negligible efficiency reduction!

Applications for TMT

- Seeing limited applications will be restricted due to the size required for the grating prisms. Other configurations might be possible.
- Diffraction limited applications would benefit from a compact, very high efficiency, and very high spectral resolution spectro-polarimeter. Likely a viable option for exo-planet spectro-polarimetry with resolutions of close to 1 million with double gratings out to wavelengths of about 2.7 microns.

Acknowledgements

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