Nanophotonics Integration for Astrophotonics

(Invited paper)

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ABSTRACT

Astrophotonics is used to reject sharp emission lines in the earth atmosphere and allows for the observation of the spectrum of faint celestial objects using earth telescopes. An integrated filter is demonstrated that can reject 47 telluric narrow OH lines and that can reach high throughput. A new type of integrated optical filter is also demonstrated that would facilitate the detection of life in the atmosphere of exoplanets with much smaller telescopes.

Keywords: integration, photonics, Bragg gratings, exoplanets, OH lines

TECHNICAL DESCRIPTION

Astrophotonics is the technology at the crossroads between astronomy and integrated nanophotonics that is used to realize more compact optical instruments.[1], [2] This technology can be used to reverse a trend of spiralling costs of instruments for larger telescopes in astronomy. It can also realize high-resolution spectrometers small enough for space telescopes. Current approaches use large lenses, mirrors and gratings. Our approach is to couple the telescope beam directly to a miniature optical-fiber-fed integrated photonic device [1]. In order to do this, one needs to use adaptive optics techniques to make the beam from the telescope to be as close as possible to being diffraction limited. Then the light goes through a photonic lantern. Multimode fibers are required to collect light that has been smeared by atmospheric turbulences. The light is then tapered down to several single mode fibers. Efficient coupling is achieved in both direction if the number m of (unpolarised) excited modes in the MMF is equal to the number of SMFs in the bundle on exit from the taper. At 1.55 µm, the number of supported modes is typically 7, so the lanterns are 1 x 7. High coupling efficiency fiber-to-waveguide couplers developed in our group are used to bring the light from the SMFs of the photonic lantern into waveguides to extract the emission lines (the telluric OH lines) that appear in ground based telescope observations. In our group, we have developed an algorithm (the layer peeling, layer adding algorithm) for making optical filters that reject 96% of the dominant near infrared lines [3]. There are several 100's of OH lines in the spectral region of interest. These lines are narrow (.1 nm) and they appear between 0.8 and 2.3 µm. For our studies, we are mostly interested in wavelengths between 1.0 and 1.7 µm. The filters that we make are based on complex waveguide Bragg gratings (CWBW) to reject narrow lines of 0.1 nm bandwidth, with a rejection ratio above 15-20 dB, while maintaining good throughput between the lines so that the spectrum can be analysed. These CWBGs suppress the OH lines before entering the spectrograph. These lines completely dominates most astronomical targets, in particular faint celestial objects of interest to us whose

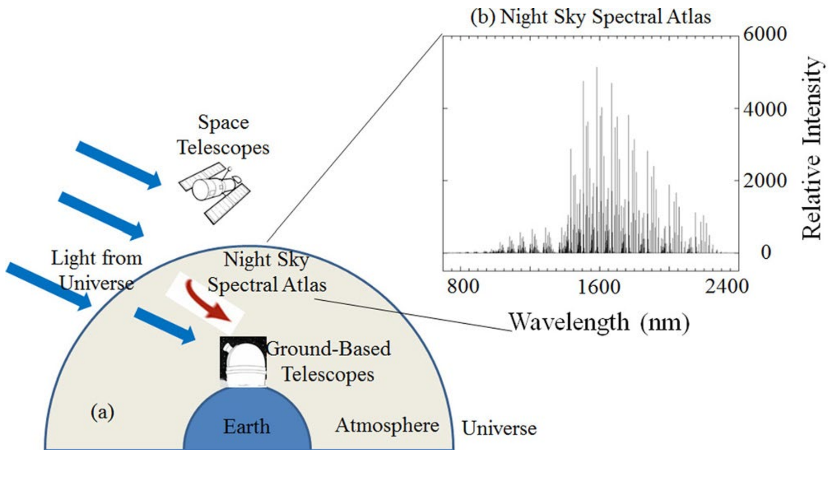

Fig. 1 Ground space telescope operation is hindered by the night sky OH emission lines in the earth atmosphere

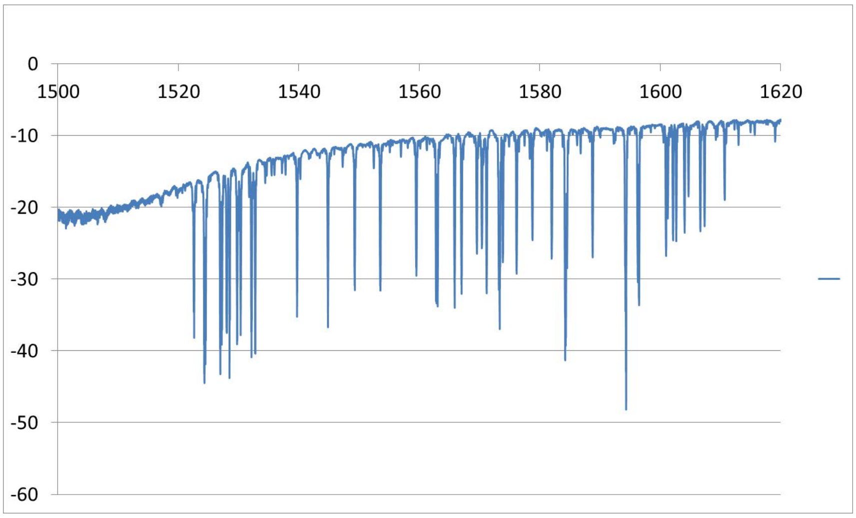

Fig. 2 A complex Bragg grating is used to reject 47 sharp spectral lines with an accuracy better than 0.1 nm over the 1522 – 1610 nm spectral range.

emission is shifted into the near-infrared spectral region due to the universe expansion following the Big Bang. After filtering the OH lines, the light is directed to an arrayed waveguide grating (AWG). The output from the AWG is dispersed vertically using micro prisms to separate the different orders and the light is finally butt-coupled to a cooled 2-dim array of detectors.

Another application of astrophotonics is directed toward searching for biosignatures in the atmosphere of exoplanets. The detection of life on another planet would be one of the greatest discoveries of all time. We would like to come up with an instrument to measure the spectroscopic signature of life in the atmosphere of exoplanets. Recently, an integrated device has been realized that allows the measurement of both the transmitted and the reflected light [4]. Such a device can be used to measure light going through the atmosphere, or reflected by the atmosphere, of a planet. By adjusting the bandwidth and location of the optical filters, it is possible to look at some spectral signature of life in the atmosphere of planets. Fig. 3 shows the calculated transmission and reflection spectrum from an earth-like planet orbiting a M dwarf star [5], [6]. By creating an optical bandpass filter to detect light in the spectral emission range of a life indicator molecule and comparing this light level with the background emission, it is possible to detect the possibility of life on a planet using a much smaller telescope.

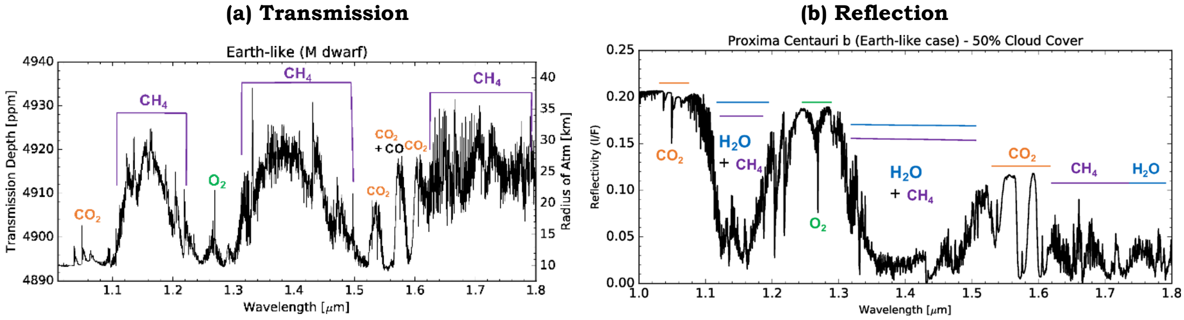

Fig. 3 (a) Transmission spectrum in parts per million (ppm) of the atmosphere of an Earth-like planet orbiting a M dwarf star. (b) Reflectance spectrum of an "Earth analog" orbiting a late M dwarf star similar to Proxima Centauri. (based on Meadows and E. Schwieterman, 2018)

We have implemented such a filter using 2 complex Bragg gratings and two multimode interference splitters. This is shown in Fig. 4.

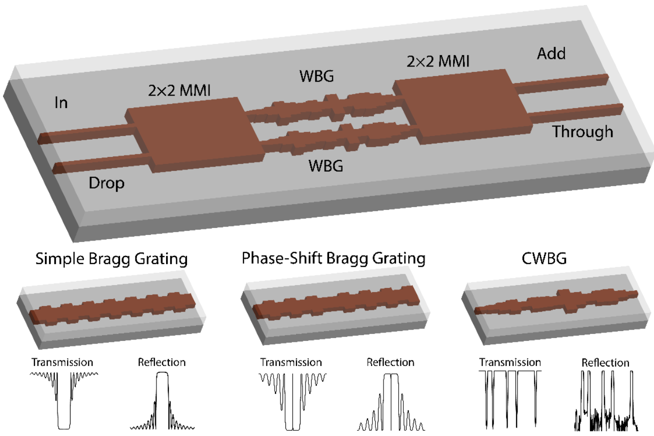

Fig. 4 Implementation of a filter with different transmission/reflection bands that can be used for exoplanet life detection.

CONCLUSION

Two applications of nanophotonic integration are presented. One application facilitates the observation of weak celestial object by rejecting the OH emission lines in the earth atmosphere. In the second application, we have proposed an integrated filter for helping the detection of life signature in earth-like planet orbiting a star.

ACKNOWLEDGEMENTS

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