An optical method for wavelength fine-selection in optical spectrum analysers

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This letter describes a novel optical method for wavelength fine-selection in the optical spectrum analysers (OSAs) for dense wavelength division multiplexing (DWDM) applications. The proposed new method employs a 'refractive optical lever' system consisting of a rotating optical wedge prism. A new OSA system based on Littman-type monochromator is proposed and the wavelength selection accuracy and resolution of OSA that has included such an optical lever system have been improved by a factor of 20 to 100 depending on the wedge angle and offset orientation angle of the optical wedge prism. This proposed 'refractive optical lever' may also simplify the rotation mechanism of the mirror in the commercially available OSAs.

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With rapid development of wavelength division multiplexing (WDM) technology, there is a need for the design of new generation optical spectrum analyser (OSA) that is suitable for field test applications[1]. These OSAs should be portable and also of high performance required for demanding dense wavelength division multiplexing (DWDM) applications (e.g. down to 25-GHz channels spacing)[2].

The traditional design of single-pass monochromator uses dispersion gratings. In this design, the input light is directed to the grating that decomposes the light into all its primary elements (wavelength). The detector, either fixed array or movable, then collects the spectra. The grating can be either rotating when the detector is fixed or fixed when the detector is movable. The single-pass OSA is a rugged device that maintains optical alignment even when it is subject to shock. However, its optical performance is limited to a small dynamic range, 3 dB at 0.4-nm from the peak central wavelength. The principles of the double-pass or quadruple-pass monochromators[3] are similar to that of single-pass one but additional components are used to send the light back to the grating two or four times before the light reaches the detector. The design is sensitive to shock and not rugged enough for field conditions and needs calibration when transported, but good optical performances, e.g. a dynamic range of more than 50 dB at 0.2 nm, are available.

An alternative design is to use the single-pass monochromator with rotating grating and a mirror as a double pass. In this case, the light is directed on a grating that rotates to sweep the entire spectral range. The light decomposed on the grating goes through a slit onto a mirror and back to the grating. The grating again diffracts the light into finer details on the detector. The system yields good performance: a dynamic range of 40 dB at 0.4 nm from peak central wavelength. However, the rotating grating is difficult to control and hard to align with the mirror and the detector. For a more rugged system, the principal components such as the grating and the detector should be fixed.

One more recent innovative design is a hybrid consisting of a single-pass OSA with no moving parts and multi-pass high-performance OSA. Littman monochromator is an example, as shown in Fig. 1. This new design uses a fixed grating with a rotating mirror. Light entering the instrument encounters the grating twice before reaching the detector. These and other patented new devices[4,5] can achieve dynamic range higher than 40 dB at 0.20 nm away from the peak and are used in the industry to take advantage of its good performance and rugged design.

It should be pointed out that all the above designs have a limited accuracy and resolution of wavelength discrimination due to use of a mechanic rotating system of a grating and a mirror. In other word, in order to achieve the required wavelength discrimination accuracy, a rather complex electronically-controlled mechanic rotating system is needed. Our current investigations aim at improving the wavelength selection accuracy and resolution of OSA based on Littman-type monochromator by using an novel optical method. The proposed optical method employs a 'refractive optical lever' system consisting of an optical wedge prism or wedge prisms system and the resulting new design of OSAs that includes this 'refractive optical lever' is described in this technical letter.

Figure 2 illustrates the operation principle of the 'refractive optical lever' consisting of an optical wedge prism. The incident beam on a wedge prism with a given wedge angle α deviates at an angle χ with respect to the incident beam propagation orientation after passing through the wedge prism.

The deviation angle χ of the beam emerging from a wedge prism varies with the beam incident angle θ on the wedge prism or the wedge prism rotation angle $\Delta\theta$

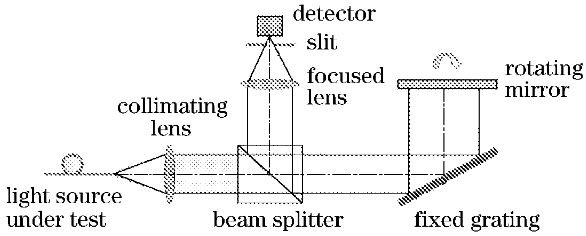

Fig. 1. Illustration of Littman-type monochromator.

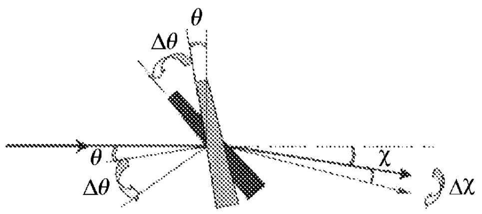

Fig. 2. Principle of the proposed 'refractive optical lever', consisting of an optical wedge prism.

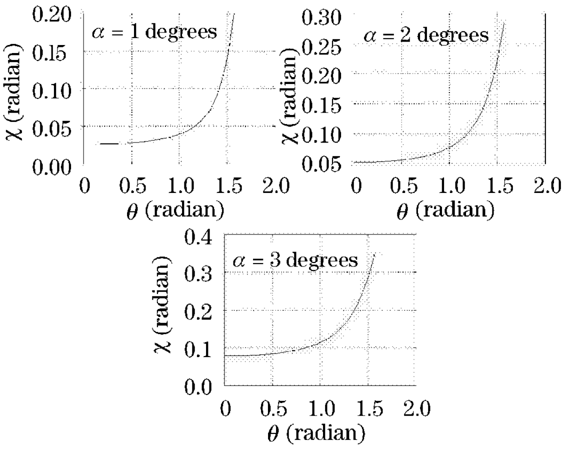

Fig. 3. Characteristics of beam deviation angle χ versus beam incident angle θ of wedge prism.

for stationary incident beam. Simple ray tracing calculations show that the beam deviation angle is a weak function of the beam incident angle when the wedge orientation is stationary or the wedge rotation angle when the orientation of the incident beam is fixed. Figure 3 shows the beam deviation angle χ varies with beam incident angle θ for several wedge prisms with wedge angles of 1, 2, and 3 degrees. Typically, when the wedge prism rotates with a few degrees around the axis perpendicular to the wedge angle plane, the resulting beam deviation change $\Delta\chi$ is only a few arc minutes. The ratio of the beam deviation angle change to the beam incident angle change, $\Delta\chi/\Delta\theta$, is used to describe the angular displacement sensitivity of the proposed 'optical lever system'.

This sensitivity is determined to be around 1/60 for a wedge prism with wedge angle of 2 degrees and given offset orientation angle of 3 degrees. However, this sensitivity can be in the range from 1/20 to 1/100, depending on the wedge angle and the offset orientation of the beam with respect to the wedge prism. Thus by rotating the wedge prism with a large angle, the beam orientation is expected to vary with a small angle. In other word, the transform of the angular displacement by the optical wedge prism illustrates the characteristics that the output beam orientation change is insensitive to the incident beam angle change. This optical transforming characteristic is here referred as an 'refractive optical lever'. The optical wedge prism functions as an optical lever in terms of its angular displacement transform. Such 'refractive optical lever' has been used in the external cavity diode laser system[6] that requires angular displacement transform system. This letter discusses another new application of this 'optical lever' in the OSAs for DWDM applications.

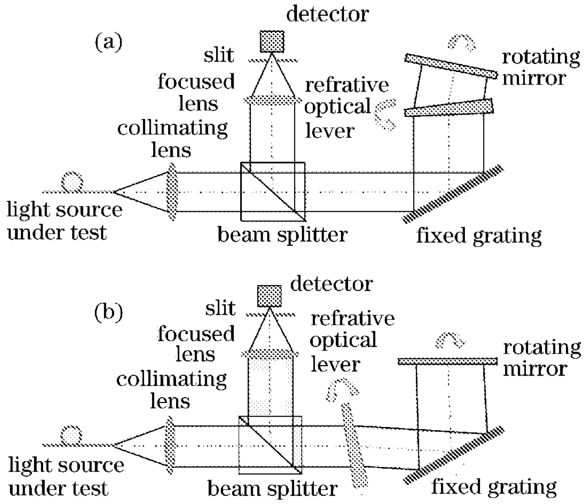

Fig. 4. (a) Littman-type OSA with a wedge prism after grating; (b) Littman-type OSA with a wedge prism before grating.

The proposed OSA system is shown in Figs. 4(a) and (b), the proposed 'refractive optical lever' is consisted of an optical wedge prism which located in the optical path between the fixed grating and the mirror (Fig. 4(a)), or between the beam splitter and the fixed grating (Fig. 4(b)).

The 'optical lever' characteristics of an optical wedge prism combined with the dispersion grating in the OSA allow us to determine the wavelength element of the light beam reaching the detector with higher accuracy and resolution. Rotating a grating or a mirror with a small angle (down to a few arc seconds) to fine select the wavelength of the light beam is equivalent to rotating the said optical wedge prism with a much larger angle (e.g. 60 times leading to a few arc minutes). This suggests that by using such 'optical lever', an extremely high wavelength discrimination accuracy and resolution can be obtained, which is difficult to obtain in the conventional direct mechanic rotating method or can only be obtained by using a fine-electronically-controlled complex mechanic rotary system. In other word, a less demanding rotating mechanism for wedge prism is required to achieve the desirable high wavelength selection accuracy and resolution than that for the rotating mechanism for the mirror and grating.

To achieve the absolute accuracy of ±5.0 GHz (or ±0.04 nm) for a typically commercial DWDM OSA[2], the tuning elements (either the grating or the mirror) need to have rotary accuracy of better than 6.5 arc seconds. However, when a simple wedge prism as a fine-tuning element is included, the required accuracy of the rotary mechanism can be relaxed by a factor of 20 to 100 to achieve the same wavelength tuning accuracy. In other word, by using a wedge prism, the wavelength tuning accuracy and resolution can be improved by a factor of 20 to 100 with the same rotary mechanism. This is a significant improvement on the wavelength discrimination capability of OSA for demanding DWDM test applications.

It is noted that the proposed 'refractive optical lever' may consist of two identical wedge prisms, one of which is stationary and the other is 'tuneable' or both of which are rotary around optic axis in opposite directions, for wavelength fine-selection. This two-wedge-prism 'optical lever' system is designed in order not to deviate the incident beam at the design centre wavelength and thus as an optical high resolution wavelength selection unit it may be incorporated in the commercially available configuration of OSAs based on Littman-type monochromators.

It should be pointed out that the rotating mirror should be used for rough wavelength selection and the rotating optical wedge prism(s) should be used for wavelength fine selection. Multiple 'optical lever' systems together with the conventional rotating mirror may be used simultaneously to achieve various wavelength selection accuracy and dynamic range of wavelength selection in the practical designs of OSAs. The advantage of this wedge prism approach is that the wavelength fine selection accuracy and dynamic range of wavelength fine selection can be optimised by choosing the wedge angle and the offset orientation angle of the wedge prism system.

In concluding, a new OSA system based on Littman-type monochromator is proposed and the wavelength selection accuracy and resolution of OSA that has included the proposed 'refractive optical lever' system is expected to be improved by a factor of 20 to 100 by choosing the wedge angle and offset orientation angle of the optical wedge prism.

It is believed that the current manufacturers of OSAs for DWDM applications or other grating-based monochromators have used fine-electronically-controlled complex mechanic rotary system to achieve desirable accuracy and resolution. The proposed novel optical wedge prism approach has offered an improved solution to wavelength fine-selection in the OSAs for DWDM applications.

The novel optical lever system for fine-wavelength tuning has been incorporated in the commercially available external cavity diode laser system[6]. The design and development of the proposed OSAs for DWDM applications using the optical lever system will be addressed in other reports.

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