for in situ measurement are known in the art. U.S. Pat. No. 5,712,710 for example, describes a probe for use in measuring the concentration of a specific metal ion dissolved in liquid. The device suffers from known problems of probe miniaturization. Either the bandwidth og the spectrometer is narrow to accommodate a small probe size, the quality of the spectral imaging is poor, or the optical processing components are large and costly. The device comprises a hand-held processing unit coupled to the probe. The processing unit is programmed to calculate and display the concentration of a specific material. In this probe, neither the photodetector nor the processing unit are integrated with the light diffraction structure. Further, the use of poor resolution in imaging the spectrum is unacceptable for most applications when using such a probe.

U.S. Pat. No. 5,020,910 describes a method of forming a light diffraction structure directly over a photodetector. The device requires external electronic circuitry to obtain a useful spectrum of light and the spectral resolution is very high in comparison to that of existing conventional spectrometers. U.S. Pat. No. 5,731,874 describes a spectrometer with an integrated photodetector. This device is sensitive only to particular spectral lines and thus is useful over a narrow spectral range.

In U.S. Pat. No. 5,742,389, Zavislan et al. disclose a Spectrophotometer and Electro-Optic Module Especially Suitable for Use Therein. The device incorporates a grating that is moveably mounted within a small housing that is capable of being held. The disclosed device concerns itself with alignment of optical components and the detector, but does not address resolution.

None of the above-described approaches permits manufacture a low cost high-resolution hand-held spectrometer. These known small spectrometric probes are frequently of complex design, resulting in increased manufacturing costs. It is, therefore, desirable to provide an autonomous simple low-cost solution where the above difficulties are alleviated. A need remains for a low-cost miniaturized spectrometric sensor/transducer with a spectral resolution comparable to that of conventional spectrometer, and capable of determining the absorbance spectral signature of a wide variety of substances in situ.

It would be advantageous to provide a small, hand-held, portable spectrometer having sufficient resolution and accuracy for use in applications where the spectrometer is installed as a sensor in a monitoring system.

OBJECT OF THE INVENTION

It is an object of this invention to provide a tool for spectrum measurement useful for in situ applications.

It is an object of this invention to provide an integrated spectrometric sensor/transducer permitting miniaturization of spectrophotometers while maintaining a sufficient amount of resolution.

It is an object of this invention to provide a low cost tool for spectrum measurement.

SUMMARY OF THE INVENTION

The resolution limitations imposed by physical size of a spectrometer are well understood. These limitations are circumvented with the use of sophisticated technologies for implementing a method of resolution enhancement for use with a low resolution grating. These methods allow for design and manufacture of portable instruments.

In accordance with the invention, a new method for providing an integrated spectrometric sensor/transducer (IISS/T) is proposed enabling in situ light-spectrum-based measurement, at a significantly reduced cost. The new method is effective. Correspondingly, IISS/T allows the manufacture of a plurality of embodiments of miniature spectrometric probes and hand-held spectrometers adapted to the different needs. For example, some are provided with wireless communication for near continuous transmission of information using wireless, or other communication systems. This is useful, in particular, for real-time industrial and environmental monitoring.

The proposed new method of the light-spectrum measurement augments measurement accuracy using digital signal processing instead of the conventional approach of improved optics and reduced noise.

According to the invention, there is provided a method of measuring a spectrum of incident light comprising the steps of capturing a spectrum of the incident light at a first resolution; digitizing the analogue measurement to provide an electrical signal; and, processing the electrical signal in order to obtain a spectrum having a higher resolution than the captured spectrum, said spectrum being an estimate of the measured light-spectrum and/or its parameters. Preferably, the optical hardware of a designed spectrometer is minimized. Further preferably, the entire method is implemented in a small hand-held device.

The proposed method of extracting information from an optical signal is more efficient than sophisticated analog processing and free of troubles characteristic thereof. It has significant advantages over optical processing. For example, though spectrometers have seen few significant advances in past several decades, digital processors are experiencing significant performance gains. With enhanced performance, more complicated and sophisticated methods may be implemented. This allows for improved performance during the upcoming years and/or further miniaturization. Further, today's semiconductor-based integration technologies allow for VLSI implementation of digital processors and optical components. Moreover, an increase in accuracy of electrical digital signal processing does not necessarily imply an increase in technological difficulties of its implementation, which is typical of optical analog signal processing.

Advantageously, the IISS/T uses low cost, low-resolution optical components. By using low-resolution optical components in the form of gratings, overall size of the device is significantly reduced. However, absent significant enhancement of spectral resolution, spectra determined using low-resolution optical components are unacceptable for many applications.

Preferably, the IISS/T comprises processing components that are functionally fused.

Preferably, a specialized digital signal processor for execution of specialized methods of spectrum reconstruction and/or of spectrum parameter estimation ensures a required quality of results.

In accordance with an embodiment of the invention, there is provided a spectrometer comprising:

a transducer comprising a dipersive element for dispersing light and a photodetector for converting the dispersed light into an electrical signal representative of spectral data, the transducer having a lower spectral resolution than 4 nm; and,

a processor for enhancing the resolution of the spectral data to provide spectral data having a resolution of at least 2 times that of the transducer.

Preferably, the spectrometer is provided with means of measuring temperature and of correcting spectra for temperature fluctuation induced errors.