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A WAVE LENGTH DETECTOR FOR MONOCHROMATIC LIGHT BEAMS

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A wavelength detector for monochromatic light beams

L. Ngo Phong
Defence Research Establishment Valcartier, Courcelette, Quebec G0A 1R0, Canada
I. Shih
Tran Teck, Brossard, Quebec J4Z 2M2, Canada

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NOTES

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L. Ngo Phong
Defence Research Establishment Valcartier, Courcelette, Quebec G0A 1R0, Canada

I. Shih
Tran Teck, Brossard, Quebec J4Z 2M2, Canada

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Wavelength detection of monochromatic light beams can be achieved with a pair of optical sensors located behind a linear variable filter. The active area of one sensor increases, whereas that of the other sensor decreases along the direction of increasing value of transmission wavelength of the filter. By computing the ratio of the photoresponse of one sensor to the other, the wavelength can be obtained from a calibration chart. Proof-of-concept wavelength detectors were constructed using photoresistive superconductor sensors. Results obtained for the spectral range of 700–1100 nm are presented and discussed. © *1996 American Institute of Physics.* [S0034-6748(96)02207-1]

Spectral measurements of optical sources can be made using an interferometer, a dispersive device, a fiber device, or a filter device. In general, interferometers and dispersive devices offer better spectral resolutions as compared to fiber and filter devices.[1] However, they are bulky and require delicate parts and frequent spectral calibrations which make them unsuited for use in a harsh environment. The use of interferometers is further limited to applications in which the incident angle of light can be accurately determined. Fiber devices, first proposed by Nicholson *et al.*,[2] consist of broadband filters, optical fibers that convert wavelength into a time delay, and sensors. For an unequivocal determination of delay time, the length of the fiber must be large so as to achieve significant time delays. In addition, a complex counting circuit must be included in the device, making the device bulky. As the device relies on counting the time delay of well defined pulses, it may not be able to discriminate wavelengths of pulsed light with a high pulse repetition frequency. Another shortcoming is this device may not easily be extended to the long wavelength ranges due to various constraints on the fiber delay lines. Filter devices comprise usually an array of optical sensors, each located behind a bandpass filter and connected to an amplifying and multiplexing circuit. The wavelength value to be detected is given by the value of the pass band of the filter. Therefore, to achieve wide spectral range or high spectral resolution, the number of filters and sensors must be large, making the device bulky and the data readout slow. The configuration of filter devices is further simplified in a device proposed by Gat,[3] in which the ensemble of bandpass filters is replaced by a linear variable filter. In this configuration, because a finite gap exists between adjacent sensors of the array, the wavelength value may be inaccurate when the position of the filter for maximum transmission of light falls within this gap. Also, as for any filter device employing a sensor array, the multiplexing time is extended when spectral range or resolution is to be increased because of the large number of sensor elements required. A long multiplexing may lead to inaccurate results in the wavelength detection of a single light pulse or repetitive light pulses with a high repetition frequency.

To eliminate the tradeoff between readout time and spectral range or spectral resolution, we propose to replace the sensor array in the Gat device with a pair of sensors—each produces a photoresponse proportional to its optically active area (in Fig. 1). The active area of each sensor (A_1 and A_2) for a specific wavelength λ is defined by the transmission area of the filter. The geometric configuration of the sensors is such that A_1 decreases while A_2 increases along the length of the filter, in the direction of increasing value of λ. In this configuration, the ratio of active areas and, accordingly, the ratio of photoresponses, is a monotonic function of transmission wavelength. Once the relation between photoresponse ratio and transmission wavelength is established, the wavelength of incoming light can be determined by measuring the photoresponses produced simultaneously by the two sensors. The main advantage of the proposed device lies in the fact that, regardless of the required spectral range and resolution, it comprises solely two readout channels so that a multiplexing circuit is not required. Such a device is suited for broadband detection of cw light, single pulsed light, and repetitive pulsed light with a high repetition frequency. The electronics are simple, and the instrumentation does not involve delicate or moving parts; this device is also a candidate for low cost, harsh field applications.

In order to investigate the proposed configuration, a wavelength detector was constructed and tested. The detector, shown in Fig. 1, consists of a pair of BiPbSrCaCuO superconductor sensors located behind a linear variable filter with a spectral range of 700–1100 nm. The sensors were used in photoresistive mode where they are broadband and produce voltage responses that increase with increasing active area. The BiPbSrCaCuO film was first deposited on a 1 cm^2 $LaAlO_3$ substrate by magnetron rf sputtering.[4] Next, a pair of line sensors with an area of $450\times50{,}000$ μm^2 was

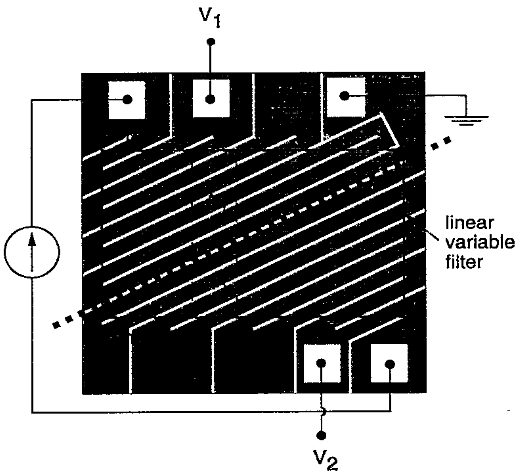

FIG. 1. Schematic configuration of the wavelength detector. The two line sensors, each defined between the voltage contact and the ground contact, are connected in series. The thick dashed line shows the separation between these sensors. The thin dashed lines delineate the active areas of the sensors which coincide with the transmission area of the filter at a specific wavelength.

created on the same substrate using standard photolithography. The sensor lines, each defined between the voltage contact and the ground contact, were connected in series to ensure that equal bias current densities were supplied to each sensor. The contact areas of the sensors were shielded from radiation (not shown in Fig. 1). Thus, optical access to the active area of each sensor was possible only through the transmission area of the filter. Referring to the inset of Fig. 2, it can be seen that the two sensors exhibit identical resistance-temperature characteristics. During the experiment, both sensors were temperature biased at the midpoint of their resistive transition ($T \sim 104$ K). Incident light with a maximum density of 5 mW/cm^2 was obtained from a calibrated monochromator chopped at 400 Hz. The voltage response generated across each sensor (V_1 and V_2) was amplified and driven to a computerized dual channel oscilloscope.

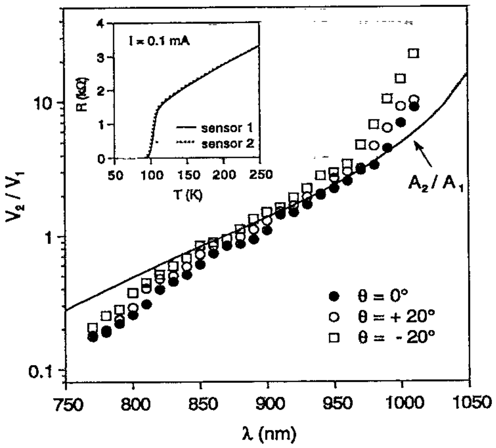

FIG. 2. Ratio of the photoresponses of the sensors as a function of wavelength for different values of the incident angle of light. The solid line depicts the wavelength dependence of the ratio of the active areas of the sensors. The inset of the figure shows the resistance-temperature characteristics of the sensors for I=0.1 mA.

In Fig. 2, the wavelength dependence of V_2/V_1 is shown for different values of θ; θ is the incident angle of the light beam with respect to the plane normal to the area and the length of the filter. The V_2/V_1 ratio is seen to increase monotonically by nearly 2 orders of magnitude over the wavelength range from 770 to 1010 nm, which is consistent with the computed wavelength dependence of A_2/A_1. The small discrepancy between these ratios may be due to an uneven spatial distribution of the incident light on the sensors. In this experiment, the beam axis coincided with the normal crossing the center of the filter area. Since the light intensity became smaller as one moved away from the beam axis, the filter may have transmitted light with a smaller intensity to the lower sensor near the left edge of the filter. Conversely, the upper sensor may have received light with a smaller intensity near the right edge of the filter. Referring to Fig. 2, this explanation seems to agree with the fact that V_2/V_1 tends to be inferior to A_2/A_1 for the short wavelengths but superior to A_2/A_1 for the long wavelengths. Results similar to the one described have been observed using a metal mask with a transmission slit to replace the filter. This suggests that the discrepancy is not due to local defects of the filter.

Although the wavelength detector was not optimized, spectral resolutions of better than 2 nm could readily be achieved assuming a fluctuation of ~5% of the voltage response. The effect of incident angle on the wavelength shift was also examined. The wavelength shift from normal incidence value, $\delta\lambda(\theta)$, has two main components: (i) a component due to a finite separation between the filter and the sensor, $\delta\lambda_S$; and (ii) a component due to the wavelength shift of the band pass value of the filter, $\delta\lambda_F$. Since $\delta\lambda_S(\theta) \approx -\delta\lambda_S(-\theta)$ and $\delta\lambda_F(\theta) \approx \delta\lambda_F(-\theta)$, the fact that $\delta\lambda(20°)$ remains inferior to $\delta\lambda(-20°)$ throughout the studied spectral range confirms that the shift is mainly due to the first component. It is interesting to note that $\delta\lambda_F(\theta)$ can be approximated as $[\delta\lambda(\theta)+\delta\lambda(-\theta)]/2$. The average value of $\delta\lambda_F(\theta)$ was estimated from the experimental data to be ~1.7%, which is of the same order of magnitude of the value specified for the employed filter.[5]

In summary, a new device for the wavelength detection of monochromatic light beams has been described. The configuration of this device can be applied to many types of sensors, provided the photoresponse of the sensor is proportional to its active area. The investigation of a superconductor wavelength detector in the spectral range of 700–1100 nm shows that spectral resolutions of better than 2 nm could be achieved. The wavelength shift with incident angle of light beam was small and could be further reduced by minimizing the separation between the filter and the sensor and by using high quality filters.

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[1] J. L. Hall and J. L. Carlsten, in *Laser Spectroscopy III. Proceedings of the Third International Conference, Jackson Lake Lodge, Wyoming* (Springer, Berlin, 1977), pp. 410–426.

[2] J. F. Nicholson, J. H. Parker, J. P. Mathur, and D. M. Hull, US Patent No. 5,225,894 (6 July, 1993).

[3] N. Gat, US Patent No. 5,166,755 (24 November, 1992).

[4] L. Ngo Phong, B. Tremblay, I. Shih, and C. X. Qiu, Supercond. Sci. Technol. **5**, 555 (1992).

[5] Optical Coating Laboratory Inc., Stock Products Catalog **5**, 55 (1994).

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