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Selective modulation interferometric spectrometer (SIMS) technique applied to background suppression

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Abstract

A method of using the SIMS (the Selective Modulation Interferometric Spectrometer) to measure the difference between the spectral content of two optical beams is given. The differencing is done optically; that is, the modulated detector signal is directly proportional to the difference between the two spectra being compared. This optical differencing minimizes the dynamic-range requirements of the electronics and requires only a simple modification of the basic cyclic SIMS spectrometer. This technique can be used to suppress background radiation for the enhancement of target detection and tracking. Laboratory measurements demonstrating the application of this technique are reported.

Introduction

The capability of optically detecting targets in the presence of a radiating background can be increased by using double-beaming techniques to suppress the effects of a radiating background. Background suppression is accomplished by ascertaining the difference in power between an optical beam from the target plus the background and an optical beam from the background only. One method of ascertaining the difference between the optical power transmitted by these two beams is to sequentially measure the power of these two beams and then compute the difference. However, this method has two serious disadvantages. First, errors may result because the difference between two numbers that are nearly equal must be computed. Second, time variation in either the instrument's response or the background conditions will cause errors because the measurements of the two beams are made at different times. Vanasse et al[1] have proposed a dual-input technique* for Fourier spectrometry that does not require computing the difference between two measurements. This paper describes an analogous double-beaming technique using the *spectromĕtre interfĕrentiel ă modulation sĕlective* (SIMS).

The SIMS was introduced by Fortunato and Marĕchal.[3,4] It has been extensively analyzed by Fortunato[5] and described by Esplin.[6] Fortunato[5] has done double-beaming with a birefringent SIMS configuration. This paper describes another method of double-beaming that uses the cyclic SIMS configuration.

A cyclic SIMS configuration is shown schematically in Figure 1. Interference fringes analogous to the fringes formed in Young's double-pinhole experiment[7] are formed in the grill plane located in the focal plane of L_2. However, in contrast to Young's configuration, the SIMS, being an interferometer, has a very large optical throughput.

The spatial distribution of the irradiance in the grill plane is analogous to the detector output of a conventional Fourier spectrometer: the SIMS forms a spatial Fourier transform of the source spectrum in the grill plane whereas a conventional Fourier spectrometer forms a temporal Fourier transform of the source spectrum.[8] The SIMS differs from the conventional Fourier spectrometer in the method used to recover the spectrum from the Fourier transform. An electromechanical method is used in the SIMS; a digital computer is used in the conventional Fourier spectrometer.

The electromechanical inversion method used in the cyclic SIMS configuration of Figure 1 is accomplished by translating mirror M_1 while vibrating the grill in the focal plane of lens L_2. For this SIMS configuration, the central wavelength of the narrow band of wavelengths modulated by the vibrating grill is determined by the location of mirror M_1. The output of the synchronous demodulator is proportional to the modulated optical power that is synchronized with the grill motion. Translating mirror M_1 causes the spectrum of the source to be plotted by the X-Y plotter. Thus, the SIMS is a simple spectrometer with real-time output.

The grill can be made by photographing the fringes which result when a monochromatic source is used. An advantage of using grills made in this fashion is that the distortion of lens L_2 is neutralized. As can be seen from Figure 1, the two optical beams which interfere to produce fringes in the SIMS share all the same optical components; and, consequently, the SIMS is a relatively rugged interferometer.

A Double-Beaming Technique Using a Cyclic SIMS

The double-beaming technique described in this paper exploits the fact that for the interferometer shown schematically in Figure 2, the fringe patterns in the focal planes of lenses L and L' are complementary; that is, the relationship between these two fringe patterns is analogous to the relationship between positive and negative photographs. The fringe pattern formed in the focal plane of lens L has a bright central fringe; the central fringe for lens L' is dark. The path difference at the center of both focal

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*First suggested by Fellgett.[2]

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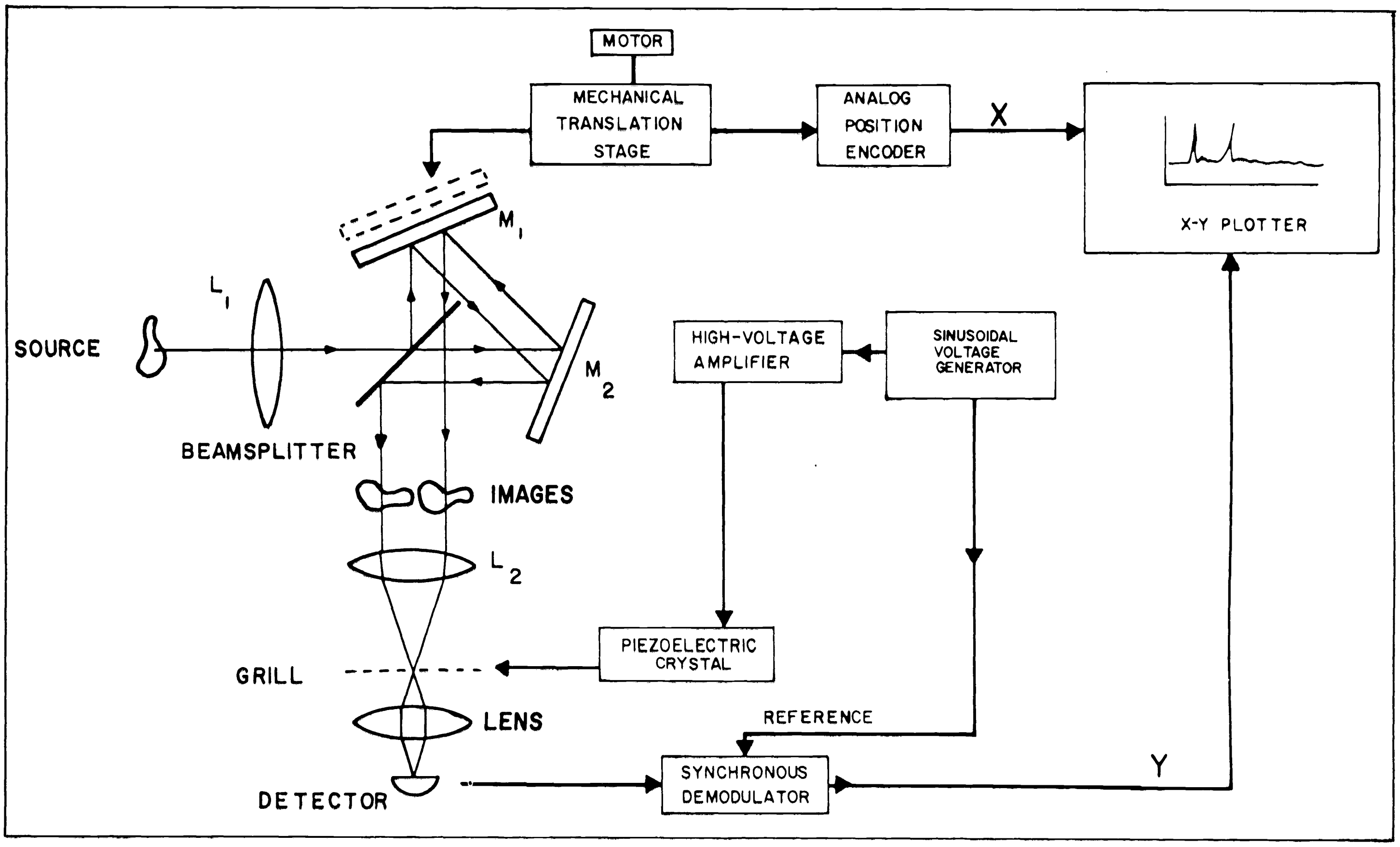

Figure 1. A cyclic SIMS configuration.

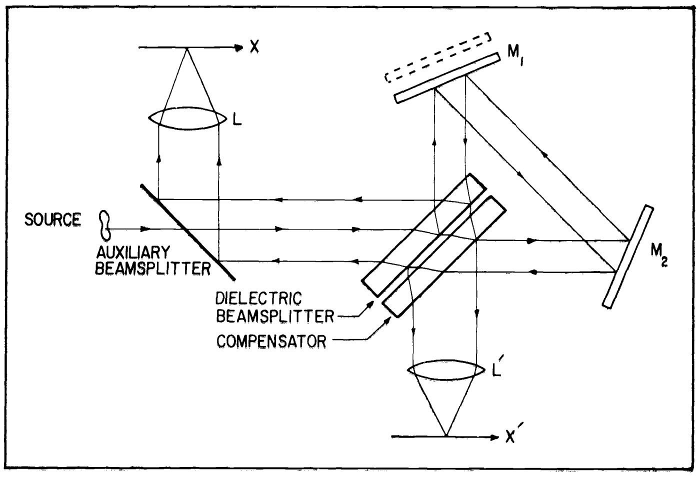

Figure 2. Schematic of the optical system of a cyclic SIMS adapted to view the fringes returned to the source.

planes is zero regardless of the position of mirror M_1. The complementary nature of these fringe patterns results because of a phase shift introduced by reflection at the dielectric beamsplitter. As illustrated in Figure 2, the two beams which interfere in the focal plane of lens L each undergo one internal reflection and one transmission at the dielectric beamsplitter. Therefore, there is no relative phase shift between the two interfering beams and a bright central fringe results. However, there is a 180 degree phase shift between the two beams which interfere in the focal plane of lens L'. One beam undergoes two transmissions at the dielectric beamsplitter, while the other beam undergoes one internal reflection and one external reflection at the dielectric beamsplitter. The two transmissions introduce no phase shift; the net phase shift introduced by the internal and the external reflections is 180 degrees. Thus, at the center of the focal plane of lens L' the two beams interfere destructively, and a dark central fringe results. The complementary relationship between the fringe patterns formed in the focal planes of lenses L and L' is illustrated in Figure 3 for both a monochromatic source and a polychromatic source. When a metallic beamsplitter was used instead of a dielectric beamsplitter, the fringe patterns were observed not to be complementary.

If the irradiance at corresponding points in the focal planes of lenses L and L' were summed, the result would be a constant. A configuration which accomplishes this summing by superimposing the two fringe patterns in the same plane is shown in Figure 4. The two fringe patterns are perfectly registered with respect to each other even if the two incident beams 1 and 2 are not in exact alignment.

This method of superimposing complementary fringe patterns can be used to convert a cyclic SIMS into a real-time double-beaming spectrometer as illustrated in Figure 5. Beam 2 consists of radiation from both the target and the background, while beam 1 consists of radiation from the background only. The two fringe patterns formed by these two beams are superimposed in the grill plane. The contribution of the background to each of these fringe patterns can be made equal by adjusting the diameter of the aperture in beam 1. The irradiance in the grill plane is the sum of these two fringe patterns. Thus, with proper balancing the spatial variation of the irradiance across the grill plane is due to the target only; the background contributes a component to the irradiance which does not vary across the grill plane. Consequently, when the grill is translated, the radiation from the target is modulated but the radiation from the background is not modulated. The radiation passing through the grill is collected onto a detector, and the time-varying component of the detector voltage synchronized with the grill motion is detected with a synchronous demodulator.

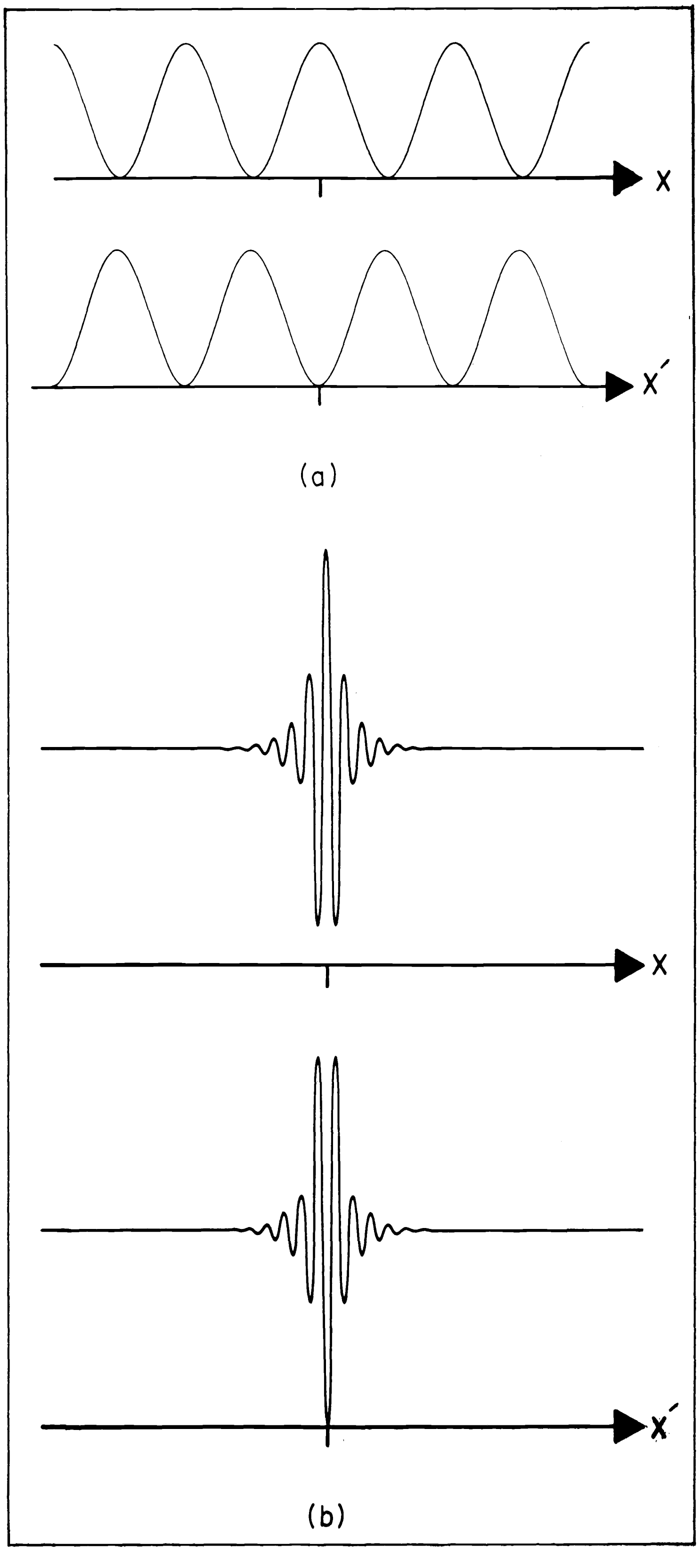

Figure 3. The fringe patterns formed in the focal planes of lenses *L* and *L*′ of Figure 2 with (a) a monochromatic source and (b) a polychromatic source.

Time-varying detector voltages that are not synchronized with the grill motion, such as could be caused by a time-varying background, are not detected. This optical method of differencing between the two beams (actually accomplished by a summing process) results in a simultaneous double-beaming spectrometer.

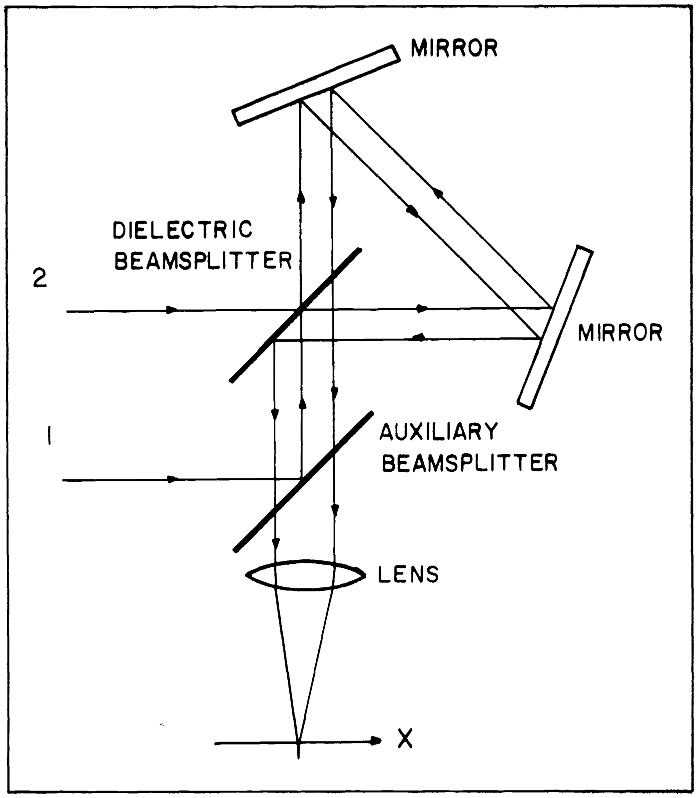

Figure 4. A configuration that superimposes the two complementary fringe patterns in one plane. Beams 1 and 2 originate from the same source.

Sequential double-beaming techniques have the disadvantage that a change in either the instrument responsivity or the background conditions between the time when the two measurements are taken introduces false structure in the spectrum computed from these two measurements. This disadvantage is particularly significant when a low intensity source is measured in the presence of a high intensity background. Figure 6 illustrates how false structure can be introduced by an unmultiplexed, sequential double-beaming spectrometer. The true spectra of the two beams are shown in parts (a) and (b) of this figure. However, either a momentary change in the instrument responsivity or in the background conditions could cause the spectrum of the background radiation to be measured as shown in (c). If (c) is subtracted from (b), the plot shown in (d), which has a false line, results. However, if a simultaneous double-beaming technique is used, the spectrum shown in part (e) is measured.

Experimental Verification

The optical system shown schematically in Figure 7 was used for preliminary measurements to verify that simultaneous double-beaming can be accomplished with a cyclic SIMS. The neon lamp was imaged in the plane of the adjustable aperture. The complementary nature of the fringe patterns formed by beams 1 and 2 was verified visually. The central fringe for beam 1 was bright; the central fringe for beam 2 was dark.

The spectral measurements shown in Figure 8 demonstrate that the output of the double-beaming cyclic SIMS due to a source that contributes energy to both beams was suppressed. The output when double-beaming was used, plot (c), was significantly smaller than when the SIMS was operated with a single beam; plots (a) and (b). The complementary relationship between plots (a) and (b) confirms the complementary nature of the two fringe patterns because a negative signal from the synchronous demodulator means that the modulated signal and the reference voltage are 180 degrees out of phase.

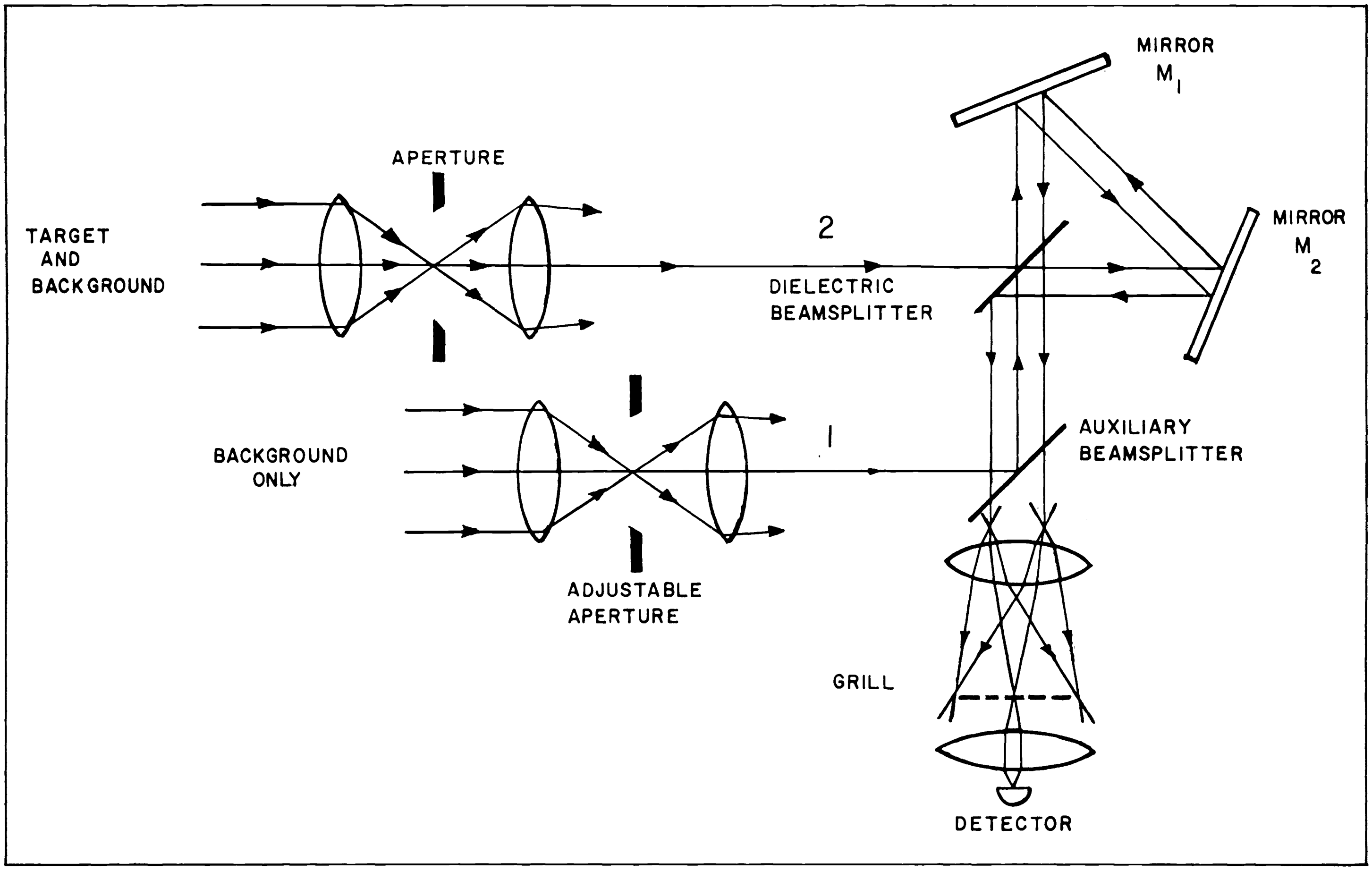

Figure 5. A double-beaming cyclic SIMS that provides background suppression.

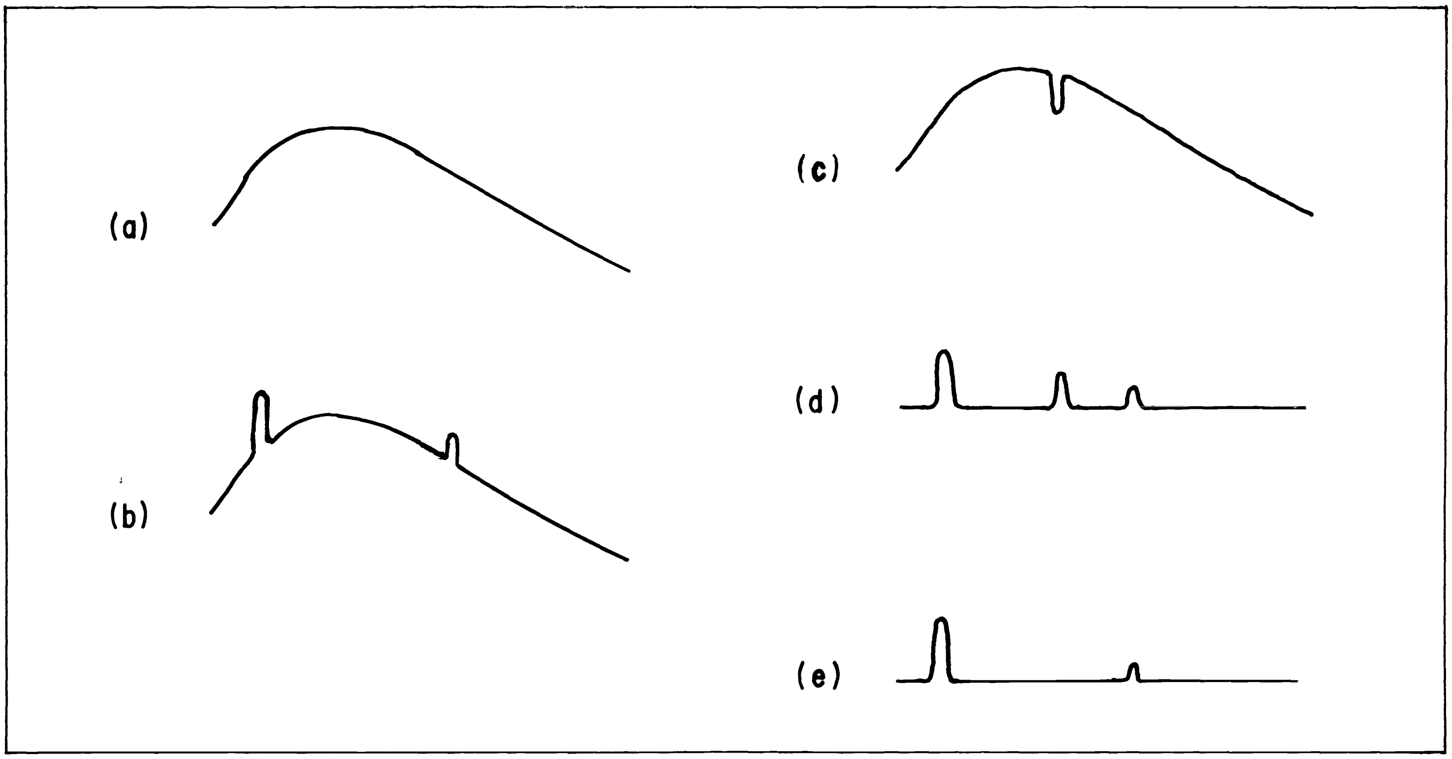

Figure 6. Synthetic spectra illustrating the effects of either a momentary change in the spectrometer responsivity or the background conditions for sequential and simultaneous double-beaming configurations of an unmultiplexed spectrometer such as the SIMS. (a) True spectrum of beam 1. (b) True spectrum of beam 2. (c) Corrupted spectrum of beam 1 due to a variation in the instrument responsivity. (d) Output of a sequential double-beaming spectrometer. (e) Output of a simultaneous double-beaming spectrometer.

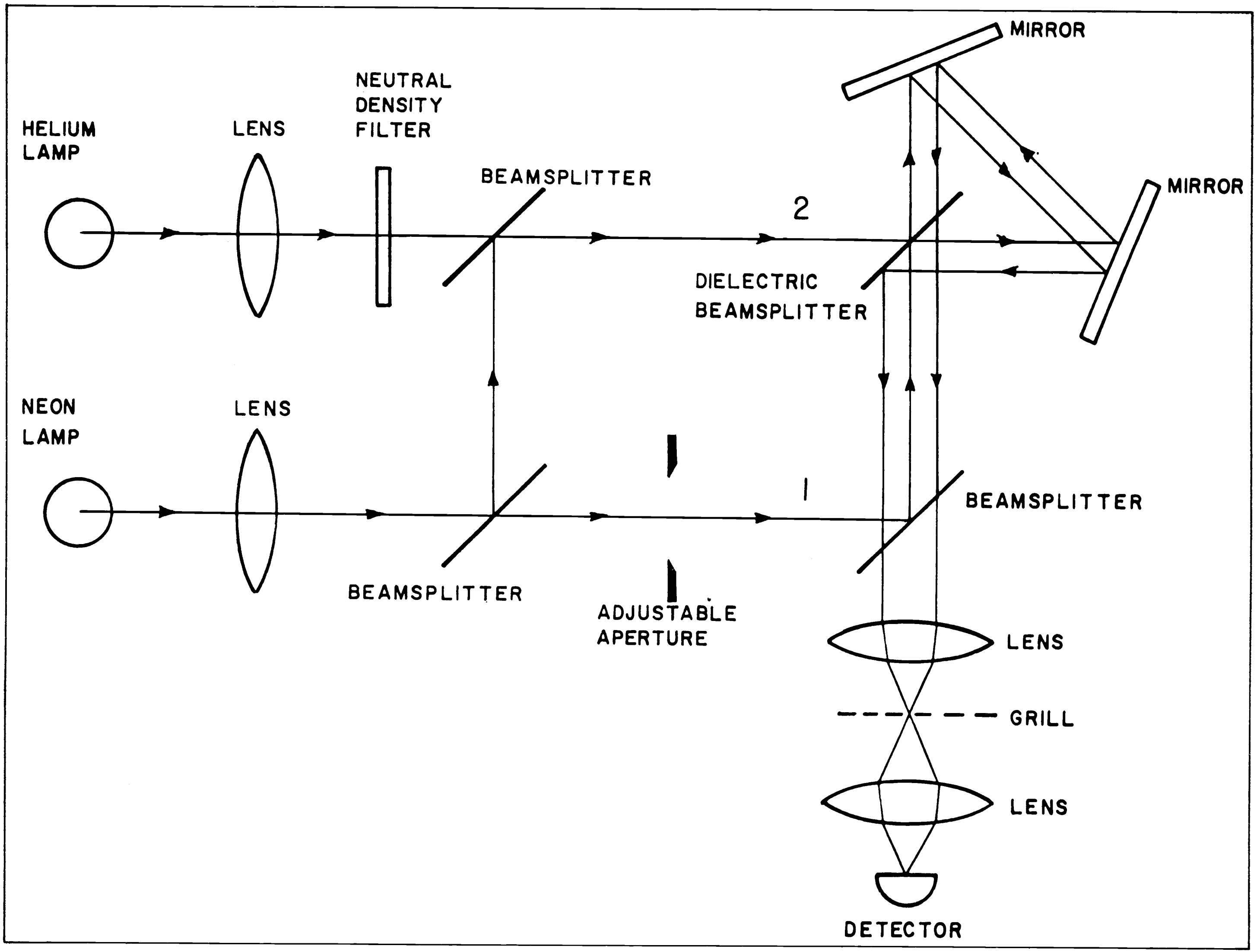

Figure 7. The optical system used to verify experimentally the cyclic SIMS double-beaming technique.

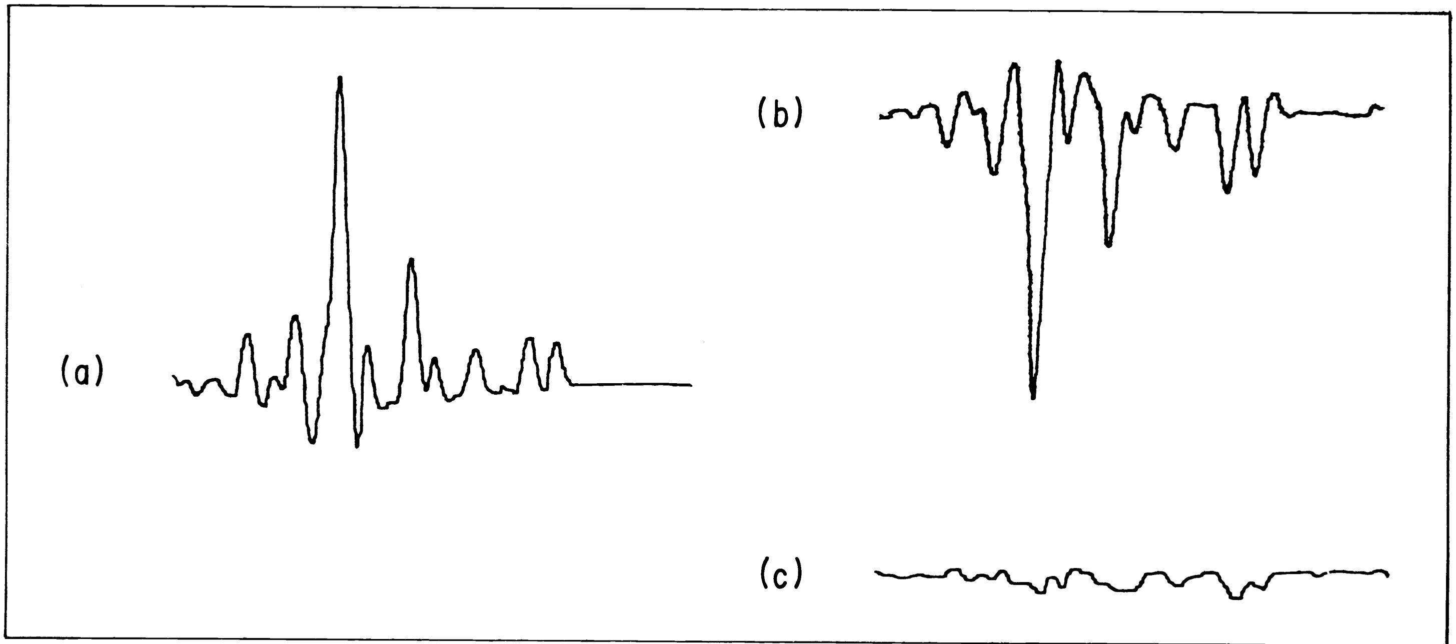

Figure 8. Measurements made with the neon lamp on and the helium lamp off. Measurements were made with (a) beam 2 only (beam 1 blocked), (b) beam 1 only (beam 2 blocked), and (c) both beams.

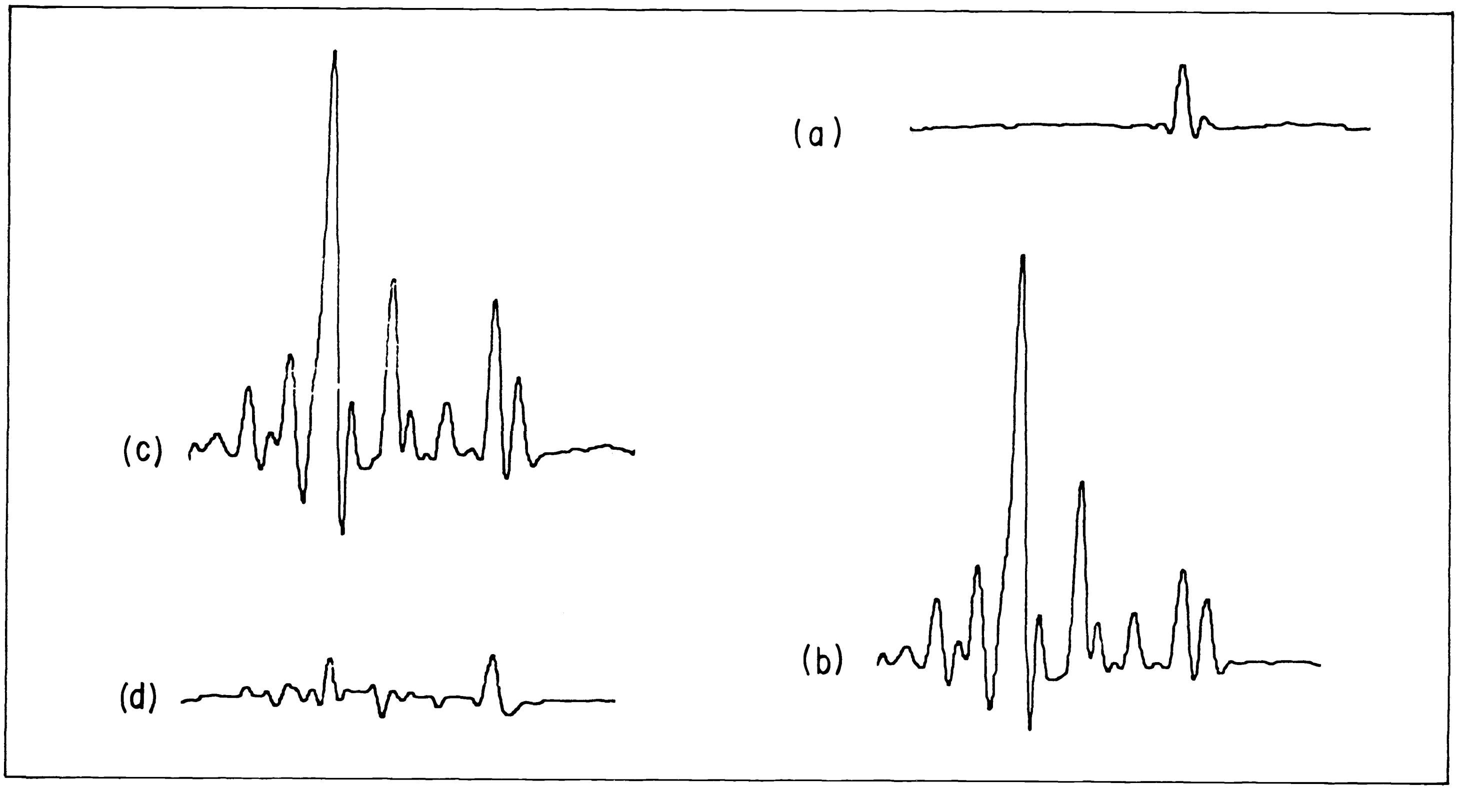

Figure 9. Measurements made with (a) the helium lamp on and the neon lamp off, (b) the neon lamp on, the helium lamp off and beam 1 blocked, (c) both lamps on and beam 1 blocked, (d) both lamps on and neither beam blocked.

Figure 9 shows the success with which a weak helium line was measured when it was superimposed on a much stronger neon spectrum. As can be seen from comparing plots (a), (b) and (c), the helium line appears superimposed on a neon line. The helium line can be clearly seen in plot (d), which was measured using double beaming.

Conclusions

By the simple modification described in this paper, the conventional cyclic SIMS can be converted into a simultaneous double-beaming spectrometer that maintains the advantages of the conventional cyclic SIMS; large optical throughput, real-time output, minimal signal-processing electronics, and ruggedness. The preliminary experimental measurements presented and discussed in this paper demonstrate that this double-beaming SIMS spectrometer can be used to accomplish background suppression. Other applications for this spectrometer are absorption measurements and pollution monitoring.

Acknowledgments

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References

1. G. A. Vanasse, R. E. Murphy and F. H. Cook, "Double-Beaming Technique in Fourier Spectroscopy," *Appl. Opt.*, Vol. 15, pp. 290–291 (1976).
2. P. Fellgett, "Spectromètre interférentiel multiplex pour measures infra-rouge sur les étoiles," *Les progrès récents en spectroscopie interférentielle; Bellevue 1957*, pp. 53–56. Centre National de la Recherche Scientifique, Paris (1958).
3. G. Fortunato and A. Maréchal, "Spectromètre interférentiel à modulation sélective," *C. R. Hebd. Seances Acad. Sci., Ser. B*, Vol. 274, pp. 931–934 (1972).
4. A. Maréchal and G. Fortunato, "Recent Developments in Selective Modulation Spectrometry," In *Space Optics: Proceedings of the Ninth International Congress of the International Commission for Optics*, eds. B. Thompson and R. Shannon, pp. 739–749. National Academy of Sciences, Washington, D. C. (1974).
5. G. Fortunato, *Etude d'un spectromètre interférentiel à modulation sélective; applications*, Thesis, a l'Universite Paris sud centre d'Orsay (1976).
6. R. W. Esplin, "The Selective Modulation Interferometric Spectrometer," *Opt. Eng.*, Vol. 17, pp. 73–81 (1978).
7. M. Born and E. Wolf, *Principles of Optics*, 3d ed. Pergamon Press, New York (1965).
8. G. A. Vanasse and H. Sakai, "Fourier Spectroscopy," In *Progress in Optics*, Vol. VI, ed. E. Wolf, pp. 259–330. North Holland Publishing Co., Amsterdam (1967).