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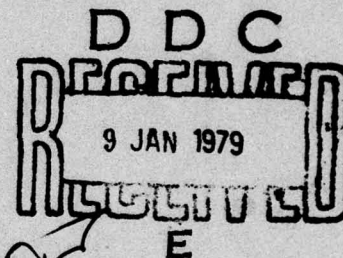


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The SIMS Technique Applied to Background Suppression

GEORGE A. VANASSE
ROY W. ESPLIN
RONALD J. HUPPI

18 September 1978



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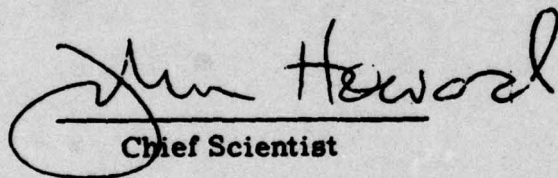
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A method of using the SIMS (the selective modulation interferometric spectrometer) to measure the difference between the spectral content of two optical beams is given. The differencing is done optically; that is, the modulated director signal is directly 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			

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20. Abstract (Continued)

background radiation for the enhancement of target detection and tracking. Laboratory measurements demonstrating the application of this technique are reported.

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Preface

This double-beaming SIMS investigation was funded by the Air Force Office of Scientific Research (AFOSR) through a contract with the Air Force Geophysics Laboratory (AFGL). The authors wish to thank Donald P. Saletnik for technical assistance in making the experimental measurements.

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The SIMS Technique Applied to Background Suppression

1. 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 the instrument's response will cause errors because the measurements of the two beams are made at different times. Vanasse et al¹ have proposed a double-beaming technique² for optical background suppression that does not have these two disadvantages. This technique does the differencing optically;

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1. Vanasse, G.A., Murphy, R.E., Cook, F.H. (1976) Double-beaming technique in fourier spectroscopy, Applied Optics, 15:290-291.
2. Fellgett, P. (1957) Spectromètre interférentiel multiplex pour mesures infrarouge sur les étoiles, Colloques Internationaux du Centre National de la Recherche Scientifique; les Progrès Récents en Spectroscopie Interférentielle, Bellevue, pp. 53-56.

the differencing is done simultaneously so the measured signal is proportional to the difference between the power in the two beams. This paper describes an analogous double-beaming technique for the spectromètre interférentiel à modulation sélective (SIMS).

The SIMS was introduced by Fortunato and Maréchal.^{3, 4} It has been extensively analyzed by Fortunato⁵ and described by Esplin.⁶ Fortunato⁵ has been 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 experiment⁷ 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 . Since the output of the synchronous demodulator is proportional to the modulated optical power, translating mirror M_1 causes the

3. Fortunato, G., and Maréchal, A. (1972) Spectromètre interférentiel à modulation sélective, C. R. Hebd. Seances Acad. Sci. Ser. B., 274:931-934.
4. Maréchal, A., and Fortunato, G. (1974) Recent developments in selective modulation spectrometry, Space Optics: Proceedings of the Ninth International Congress of the International Commission for Optics, pp. 739-749.
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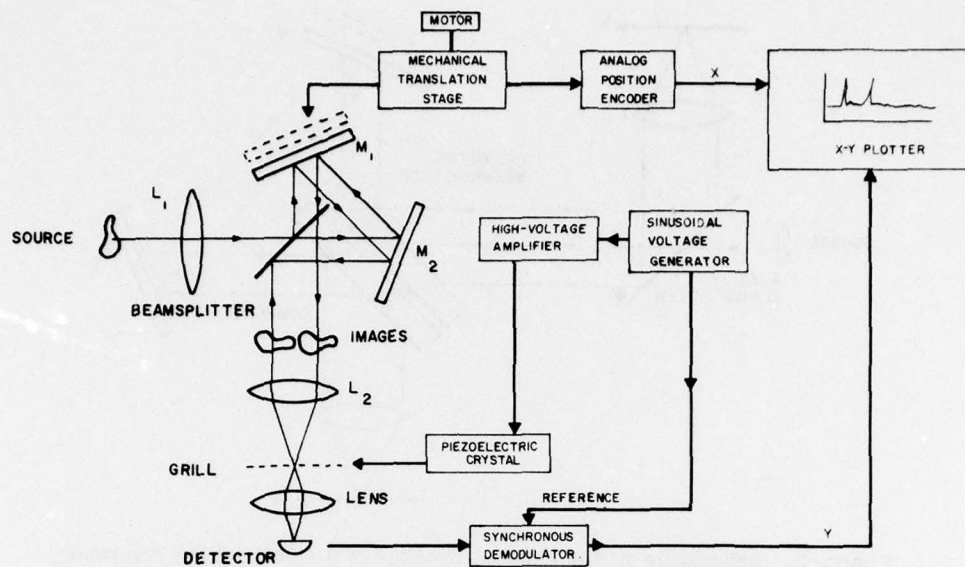


Figure 1. A Cyclic SIMS Configuration

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.

2. 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. This complementary relationship is illustrated in Figure 3, both for a monochromatic source and a broadband, polychromatic source. The fringe pattern formed in the focal plane of lens L' has a dark central fringe; the central fringe for lens L is bright. The complementary nature of the fringe patterns can be explained in terms of phase shifts introduced by reflections at the

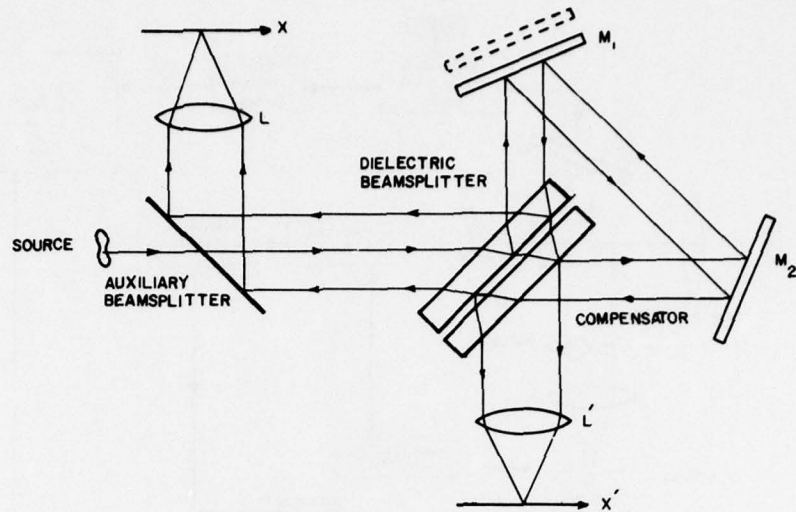


Figure 2. Schematic of the Optical System of a Cyclic SIMS Adapted to View the Fringes Returned to the Source. Lenses L and L' have equal focal lengths

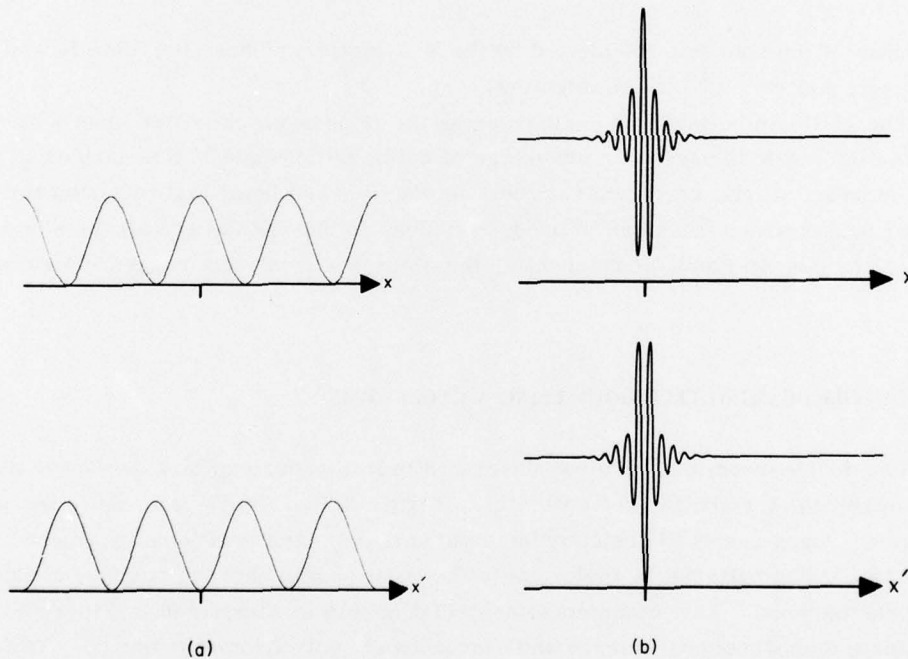


Figure 3. The Irradiance Distribution in the Focal Planes of Lenses L and L' in Figure 2 for (a) A Monochromatic Source and (b) A Wideband, Polychromatic Source

dielectric beamsplitter. As can be seen from Figure 2, the two beams which interfere in the focal plane of lens L each undergo one internal reflection at the beamsplitter. Thus, there is no optical path difference at the center of the focal plane of lens L; this condition exists regardless of the displacement of mirror M_1 . Consequently, the central fringe is bright. However, for the two beams which interfere in the focal plane of lens L', the dielectric beamsplitter introduces a 180 degree phase shift. One beam undergoes no reflections at the dielectric beamsplitter, while the other beam undergoes one external reflection and one internal reflection at the dielectric beamsplitter; this external reflection introduces a 180 degree phase shift. Thus, at the center of the focal plane of lens L' the two beams interfere destructively and a dark central fringe results. When the dielectric beamsplitter in Figure 2 was replaced by a metallic beamsplitter, the two fringe patterns were observed not to be complementary.

If the irradiance at corresponding points in the focal planes of lenses L and L' could be 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. Even if the rays 1 and 2 do not intersect as shown in Figure 4, the two fringe patterns are still perfectly registered with respect to one another and the irradiance is constant across the focal plane of the lens.

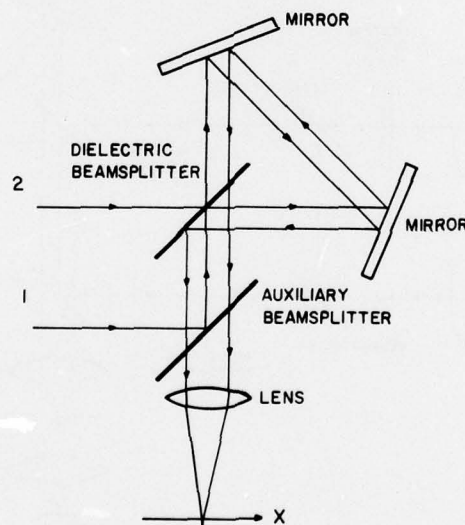


Figure 4. A Configuration That Superimposes Two Complementary Fringe Patterns in One Plane. Rays 1 and 2 originate from the same source

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. The beam introduced by the auxiliary beamsplitter contains power from the background only, while the other beam contains power from both the target and the background. Only the power from the target causes irradiance variations across the grill plane; the background contributes only a constant irradiance. Thus, the ac component of the detector output voltage is due to the target only. Differencing between the two beams (actually accomplished by a summing process) is done optically. The adjustable aperture provides a means of balancing. This can be accomplished by orienting the SIMS so that both beams contain energy from the background only and then adjusting the aperture size for a null output voltage from the synchronous demodulator.

Sequential double-beaming techniques have the disadvantage that a change in the instrument responsivity between the time when the two measurements are taken introduces false structure in the measured spectrum. This effect is particularly significant when a low intensity spectrum is measured in the presence of a high intensity spectrum. The synthetic spectra shown in Figure 6 illustrate how false structure can be introduced by a time-varying instrument responsivity. The true spectra of the two beams are shown in parts (a) and (b) of this figure. However,

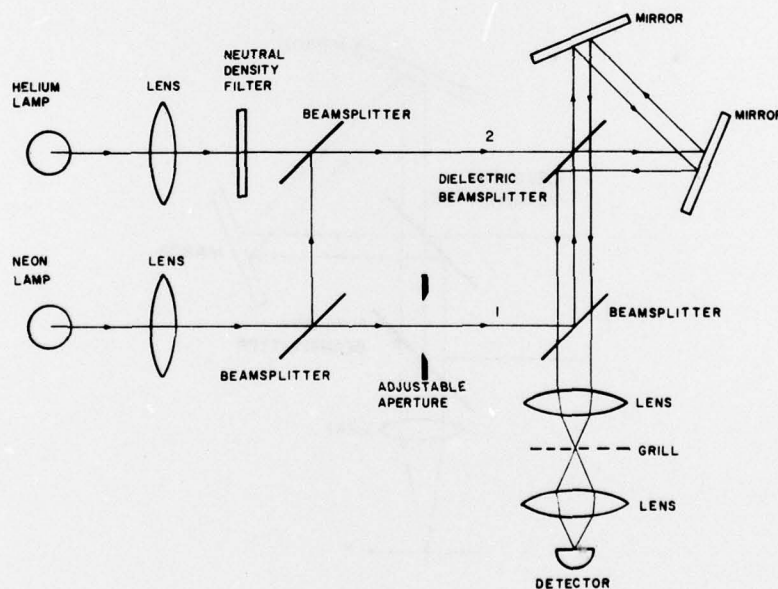


Figure 5. The Optical System of a Double-beaming Cyclic SIMS That Suppresses Background Radiation

a time-varying instrument responsivity, such as a vibration of the grill in the SIMS, 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 the simultaneous double-beaming technique shown in Figure 5 is used, the spectrum shown in part (e) of Figure 6 is measured.

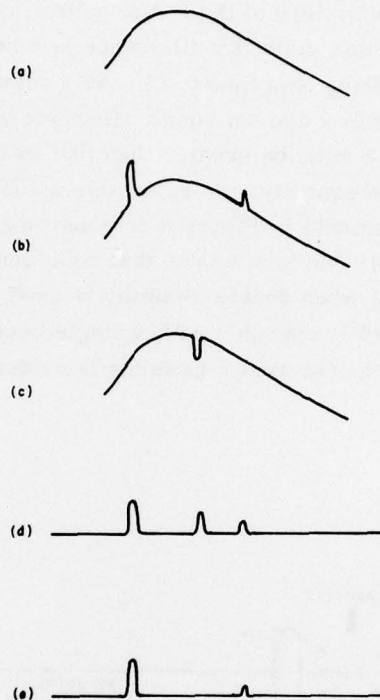


Figure 6. Synthetic Spectra Illustrating the Effects of Time Variations in Spectrometer Responsivity for Sequential and Simultaneous Double-beaming Configurations. (a) True spectrum of beam 1. (b) True spectrum of beam 2. (c) Corrupted spectrum of beam 1 due to a variation in the instrument responsivity. (d) Output of a sequential double-beaming spectrometer. (e) Output of a simultaneous double-beaming spectrometer

3. 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 is bright; the central fringe for beam 2 is dark. The visibility of the fringe pattern of beam 1 is greater than for the pattern of beam 2; this visibility difference is a result of the dielectric beamsplitter RT product being less than 0.25. As a result, the amplitudes of the interfering waves from beam 2 are not equal. Because of this difference in visibility, the power in beam 2 must be greater than that in beam 1 in order to achieve a balanced condition. Consequently, the adjustable aperture was located in beam 1.

The spectral measurements in Figure 8 demonstrate that the output of the double-beaming cyclic SIMS due to a source that contributes energy to both beams is suppressed. The output when double-beaming is used, plot (c), is significantly smaller than when the SIMS is operated with a single beam, plots (a) and (b). The complementary nature of the two fringe patterns is evident in the complementary

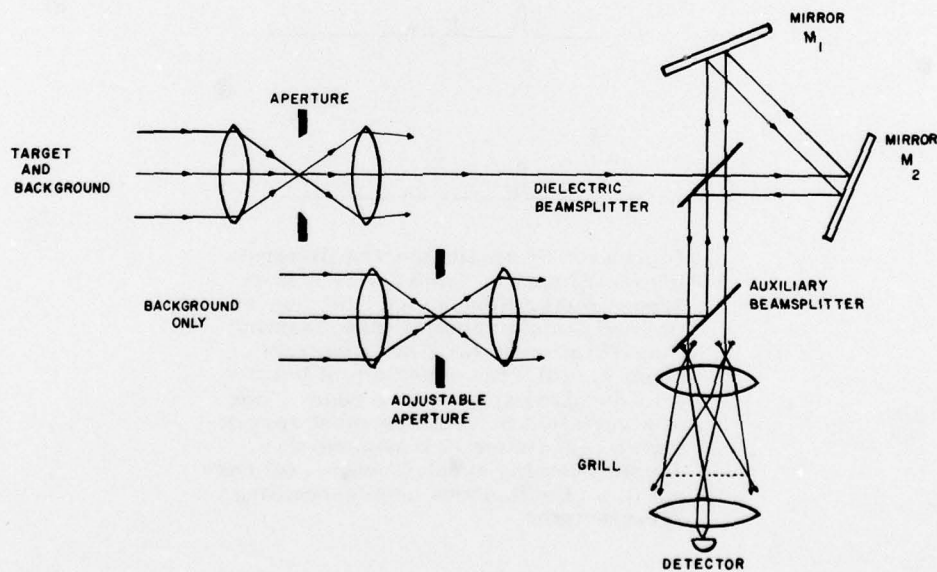


Figure 7. The Optical System Used to Experimentally Verify the Cyclic SIMS Double-beaming Technique

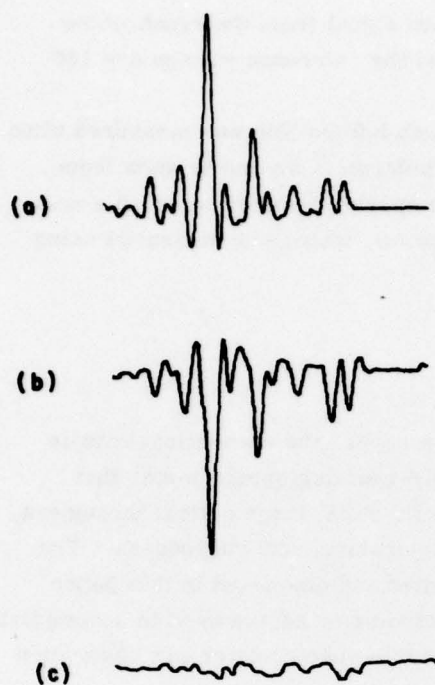


Figure 8. Measurements Made With the Helium Source Off and (a) Beam 2 Only, (b) Beam 1 Only, (c) Both Beams

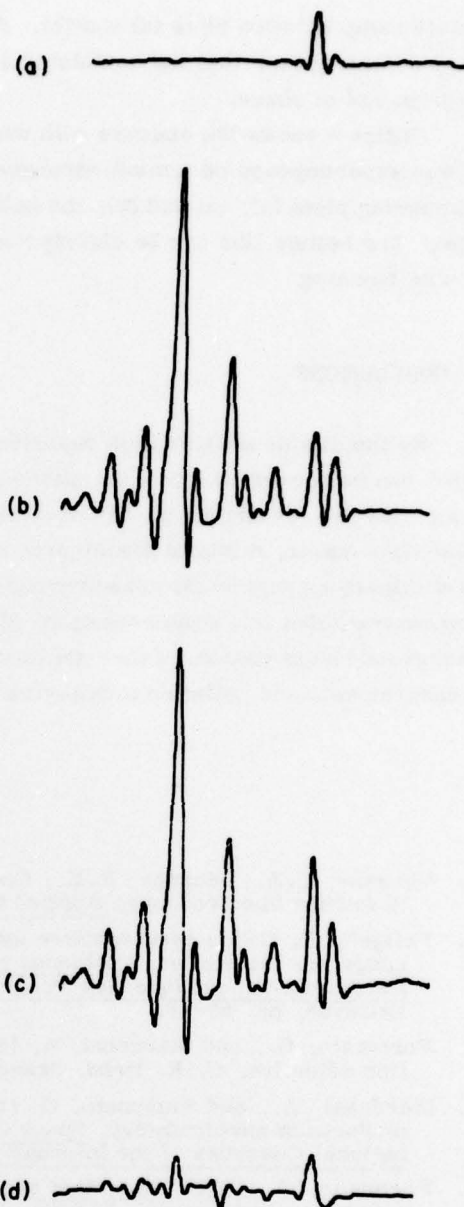


Figure 9. Measurements Made With (a) The Neon Lamp Off and Beam 1 Blocked, (b) The Helium Lamp Off and Beam 1 Blocked, (c) Both Lamps On and Beam 1 Blocked, (d) Both Lamps On and Neither Beam Blocked

relationship between plots (a) and (b). A negative signal from the synchronous demodulator means that the modulated signal and the reference voltage are 180 degrees out of phase.

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.

4. 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.

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