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A HIGH RESOLUTION INTERFEROMETER FOR USE WITH SYNCHROTRON RADIATION

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ABSTRACT

We present the first results from a new instrument which is designed to work ,at very high resolution in the infrared spectral region but whose principles can be used in the vuv/soft-xray region. The instrument is based on an interferometer. For the vuv/soft-xray region the beamsplitting is achieved by wavefront division which takes advantage of the spatial coherence of synchrotron radiation. Normally the highest frequency in the spectrum from an interferometer is determined by the sampling frequency, which has to be at least twice that of the highest frequency in the spectrum. We show that this can be avoided if the spectral range is deliberately restricted by a grating or by the use of an undulator. In this case the interferograms contain a known and restricted range of frequencies which lead to an unambiguous assignment during the Fourier processing required to generate the spectrum.

INTRODUCTION

The development of infrared synchrotron at the NSLS[1,2], has utilized Michelson and Lamellar interferometers for spectral analysis. The latter led to a new instrument in which the spatial coherence of the infrared synchrotron radiation was utilized by deriving two beams for the interferometer by physically dividing the wavefront emerging from the ring[3].

We now present details and preliminary results from a new instrument which can be operated either using a wavefront dividing beamsplitter or using conventional amplitude dividing beamsplitters.

THE INTERFEROMETER

(a) Resolution.

The crucial component of the new instrument is shown schematically in Fig. 1 and in the photograph of Fig. 2. The actual instrument is installed in a large vacuum tank capable of operating at a vacuum of 10^{-2} torr. It is called a Mach-Zender interferometer because it has two "beamsplitters" - one for separating the two beams and one for recombining them. It is also a multiple path interferometer in which the central pillar moves, thus shortening the path length on one side while lengthening it on the other. The beam makes a total of 10 passes per side, which means that the maximum path difference is 20 times the maximum travel (15cm) of the central column. The instrument can be used in two ways - in one of which the central column travels ±15 cm to generate double sided interferograms of maximum resolution Δv of 1/600 cm^{-1} or .0017 cm^{-1}. (The resolution of an interferometer is 1/2L where L is the maximum path difference[4]). In another mode the zero path difference position can be shifted to the edge of the scan range of the central column by moving one of the end columns out by 30cm. The maximum path difference then is 600cm giving a maximum

resolution, Δv, of 1/1200 cm^{-1} or .0008 cm^{-1}.

(b) Wavelength Range (Highest Measurable Frequency)

An equally important consideration for interferometers and one which assumes significantly more importance in a vuv interferometer is the highest frequency measurable with a given instrument. This is related to the sampling interval while the central pillar is moved. Information theory states that the measuring interval must be at least twice that of the highest frequency present. Since, in this instrument, the path is multiplied, the sampling interval is also a multiple of the actual distance traveled by the central column. As an example, if we wish to obtain a spectrum up to 1000 cm^{-1}, then we have to sample the modulation at twice that frequency. Since for $v=1000$ cm^{-1}, $\lambda=10$ μ, then we would have to sample every 5 μ of optical path difference, or for each central pillar displacement of 0.25 μ. This makes the instrument more challenging from a mechanical engineering point of view but may be obviated in the following way.

If the input spectrum is reduced in width, but if the spectral band is chosen such that its maximum frequency v_{MAX} is equal to an integer, f, times its width, Δv, then the sampling interval can be chosen to be f times larger[5]. The maximum path difference is the same but fewer data points are taken as one is sampling the sub-harmonics of the actual spectrum. The Fourier transform turns out to be unambiguous, provided the above conditions are met. It is especially important that there be no spectral information between the band being measured and zero frequency.

In order to prepare for this we used a grating spectrometer between the interferometer and the detector. Clearly the angle of the grating could be used to select the center of a band whose width could be determined by the size of a slit.

DISCLAIMER

RESULTS

In order to test the instrument we measured the absorption spectrum of ammonia[6]. The sample was in a meter long gas cell, which was an integral part of the experimental arrangement lying between the interferometer and the grating. The gas cell had a spherical mirror to refocus the light from the entrance spot to the exit spot. Ammonia was chosen since it has a series of rotational bands, separated from each other by about 20 cm^{-1} starting at 40 cm^{-1}.

In Fig. 3 we show the spectrum obtained over the region 0-200 cm^{-1}, in which 7 of these bands can clearly be distinguished. We also point out "artifacts" due to the 50 μ mylar beamsplitter at ~65 cm^{-1}, and due to a quartz filter at ~127 cm^{-1}. This spectrum was taken at a resolution of 3.56 cm^{-1} and using 128 points, at one point per second.

As a verification of the ability to define a spectral bandpass using a grating, (to enable higher frequencies to be measured more easily), we show in Fig. 4 a spectrum of another ammonia sample in the range 0-250 cm^{-1} in which it can be seen that spectral information is only present in the 10-60 cm^{-1} region. This region was defined using an echelette grating of 10 lines per mm. blazed at 29° (λ_B = 42 μ, 238 cm^{-1}). The resolution of this spectrum was 3.8 cm^{-1}. At these low frequencies it was not necessary to use the sub-harmonic method described earlier to attain higher resolution. We can demonstrate higher resolution, however, by running at a maximum path difference corresponding to a δv of .325 cm^{-1} and shown in the insert to Fig. 4. In this spectrum we were able clearly to resolve the J=1 line at 40 cm^{-1} into a doublet caused by the inversion of the molecule.

DISCUSSION

We have built a novel instrument for the far infrared spectral region in the range 1-400 cm^{-1} which comprises both an interferometer and a grating. The combination will

enable high resolution spectra to be obtained at higher frequencies using fewer data points. The instrument operates completely in vacuum and is equipped with a 1 meter long gas cell. We have demonstrated the performance of the instrument by measuring the absorption of ammonia gas.

ACKNOWLEDGEMENTS

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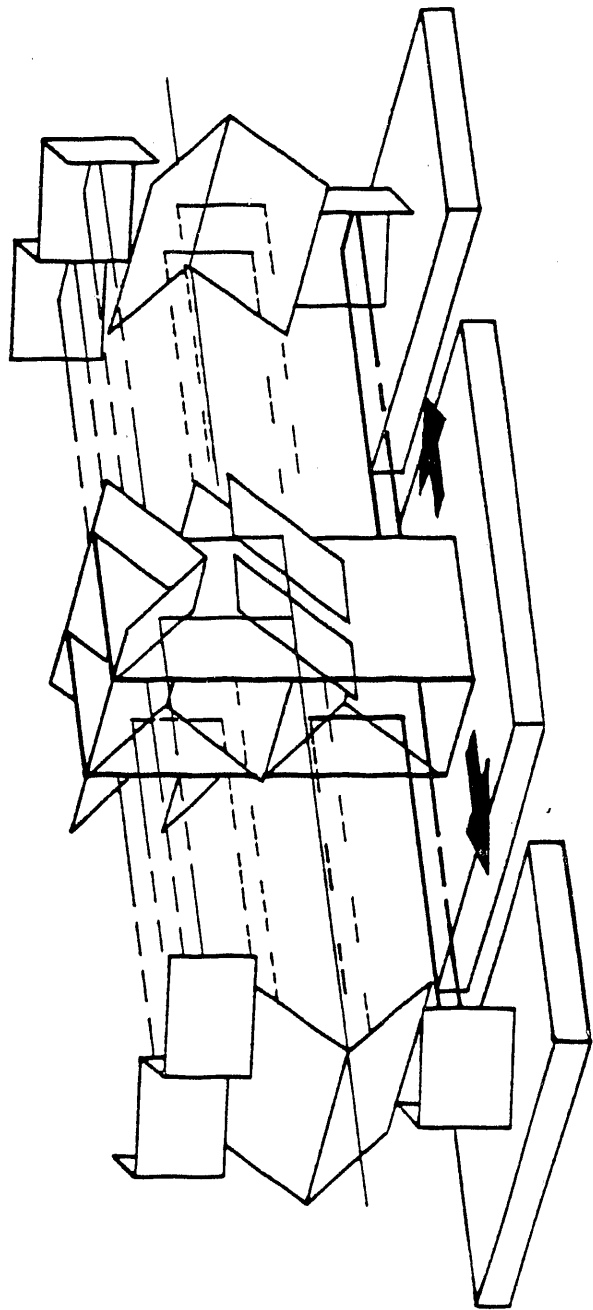
FIGURE CAPTIONS

Fig. 1. Schematic of the Mach-Zender interferometer. The light makes 10 passes on either side of the central column, which moves to change the path lengths.
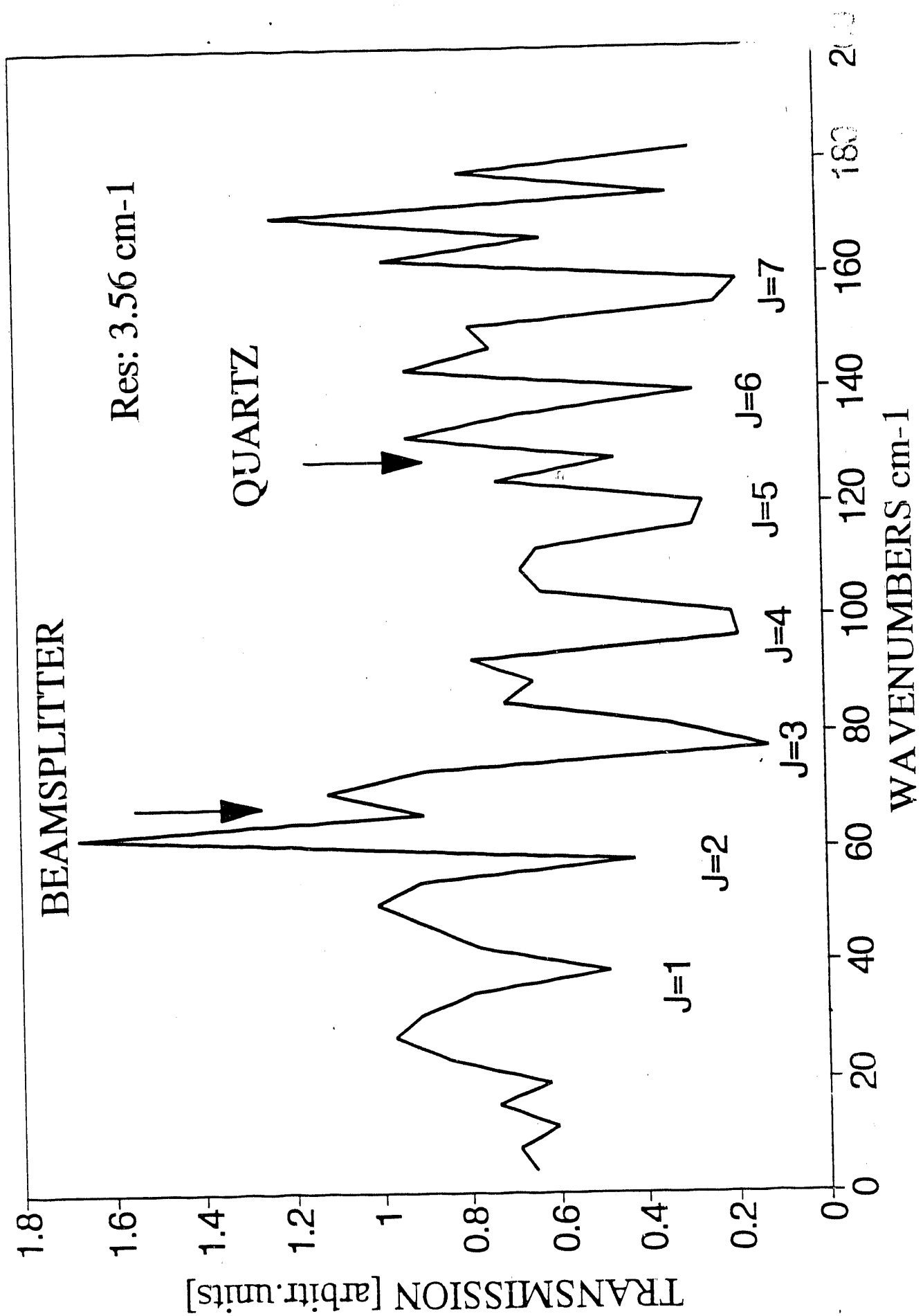
Fig. 2. Photograph of the interferometer section shown in Fig. 1, which is at the heart of the present instrument.
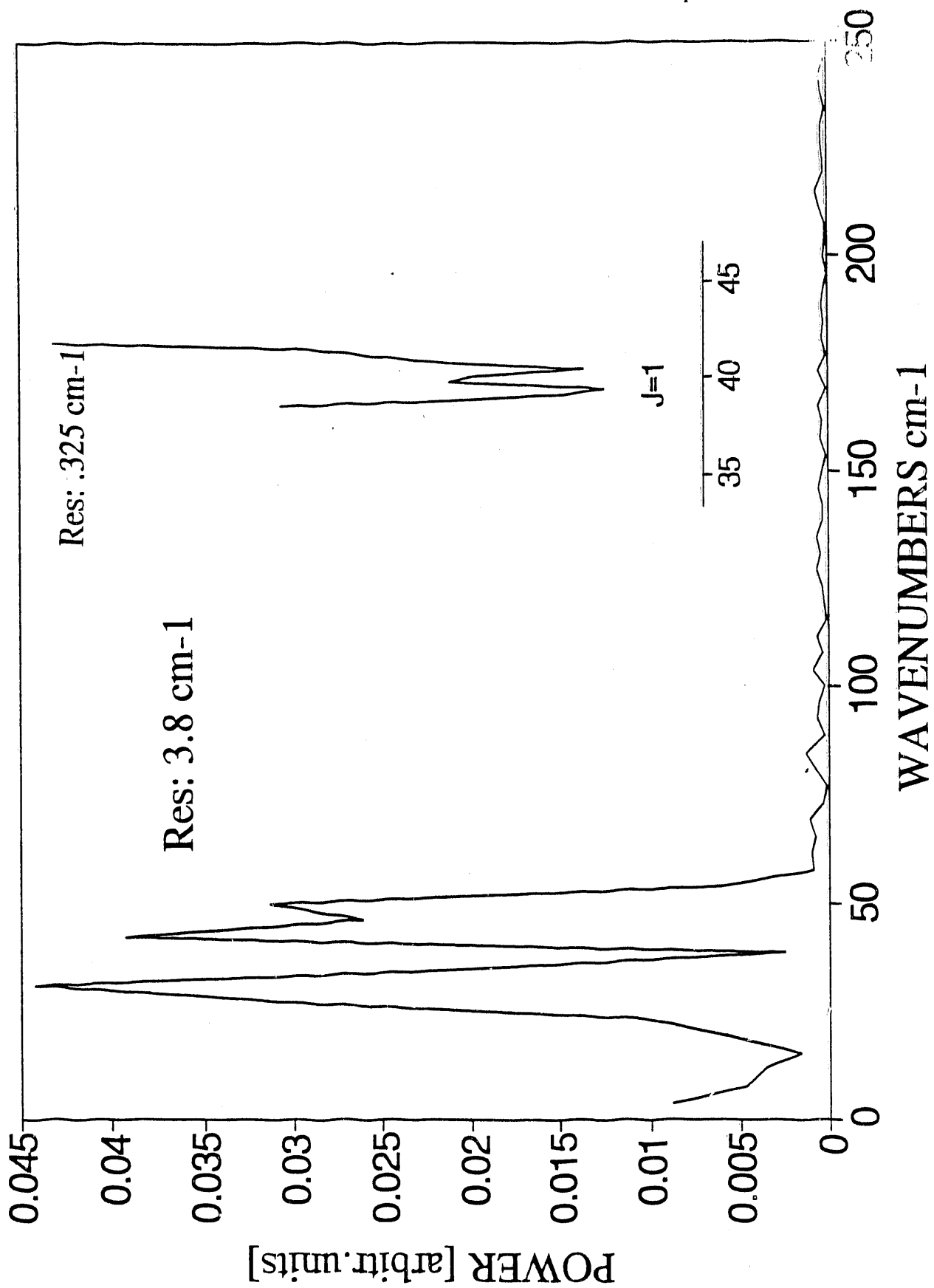
Fig. 3. The pure rotational spectrum of ammonia gas as measured by the U4IR Mach-Zender interferometer. 7 lines are seen and labeled. In addition two features appear as artifacts due to the quartz filter and to the beamsplitter.

Fig. 4. The spectrum obtained by a combination of the interferometer and the grating. The latter defines the more limited bandpass seen. In the inset is seen a narrow region measured at higher resolution and in which the inversion splitting of the first rotational band can be seen.

Res: .325 cm-1

Res: 3.8 cm-1

J=1

35   40   45

0   50   100   150   200   250

WAVENUMBERS cm-1

POWER [arbitr.units]

0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0

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