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APPLICATIONS OF THE OPTICAL MULTICHANNEL ANALYZER FOR 1.) LOW LIGHT LEVEL SIGNAL AVERAGING AND 2.) 2-D MODE DETECTION OF PICOSECOND LASER GENERATED RAMAN SPECTRA

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APPLICATIONS OF THE OPTICAL MULTICHANNEL ANALYZER FOR 1.) LOW LIGHT LEVEL SIGNAL AVERAGING AND 2.) 2-D MODE DETECTION OF PICOSECOND LASER GENERATED RAMAN SPECTRA

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Abstract

Techniques developed for the use of a programmable optical multichannel analyzer (OMA) are discussed. Two different signal-limited areas which are of general spectroscopic interest are the focus of the paper. The first area involves using extended delay target integration techniques for low level light signal averaging. The second application area describes techniques developed for capturing spectral information from pulsed laser experiments. Multiple tracks are shown in order to demonstrate the 2-dimensional applications in spectroscopy. The paper contains much useful information about the design and operating principles behind vidicon detectors and considers other imaging technologies as well.

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I. INTRODUCTION

The use of the optical multichannel analyzer (OMA)[1] has become a powerful instrument for high-speed photodetection in atomic and molecular spectroscopy. The many diverse applications of this instrument which have received considerable attention include the areas of electron and mass spectroscopy, laser diagnostics, pulsed X-ray crystallography[2], biomedical instrumentation[3,4], LEED, and also time-resolved streak cameras[5] and other gating[6,7,8] techniques. This report directs its attention towards the use of the OMA as a spectroscopic instrument for scientists. We would like to address two very specific areas dealing with signal-limited applications, namely the use of the OMA as an instrument for the signal averaging of very weak light emissions and secondly for its use to capture spectral information in transient pulsed laser experiments.

The optical multichannel analyzer (OMA 2) from PARC[9] represents a second generation instrument which is fully programmable and may be interfaced to any of a number of 16-bit computers. The use of a Digital Equipment Corporation (DEC) LSI-11 microcomputer through a 16-bit parallel interface to the OMA for processor-controlled signal averaging has been demonstrated.[10,11] While a wide variety of detectors are available, in most spectroscopic applications, the 500x500 diode array SIT (silicon intensified target) or ISIT (intensified silicon intensifier target) tubes are recommended. Besides being fully programmable, the improved OMA 2 provides for a very large A/D dynamic range (10,000 counts) as well as a much better charge-sensitive preamplifier section which greatly reduces electronic readout noise. The flexibility gained from computer programmability, for example, can be quite substantial since the ability to optimize detector scan and readout parameters is an absolute requirement for obtaining good S/N measurements from low level light signals. In addition, the ability of the computer to perform image enhancement, baseline renormalization, and statistical treatment of the data completes the signal processing capabilities of these detectors.

In this paper, techniques developed in our laboratory for performing optical spectroscopy in two signal-limited areas are presented. The first area addressed is low light level CW optical emissions where extended delay target integration techniques are required. The second area considers the capture of spectral information in a pulsed optical transient experiment, particularly in a picosecond Nd:glass laser experiment for the study of vibrational dephasing in condensed phases.
The statistical treatment in these two cases is based on the consideration of the limitations of the signal rather than that of the detector.

In order to present the salient features of this article, a brief introduction into the theory of the SIT & ISIT detectors and a description of the principles behind their operation will be discussed first. Since the characteristics and specifications for OMA vidicon detectors are readily obtainable [12,13,14,15], this paper will be limited to only those comparisons which are of special interest. After presenting the details of the two signal-limited areas, and examples of spectra collected using these methods, other potential uses for these instruments will be shown. Finally, information about other imaging technologies and their suitable applications for those solid state devices will be presented.

II. THEORY OF SIT AND ISIT DETECTORS

The silicon intensified target (SIT) detector is based primarily on the existing television vidicon technology. The detectors available include UV/VIS response as well as some which have extended IR sensitivity. By the addition of one or two image intensifier stages, as in the SIT & ISIT detectors, respectively, their sensitivity and response is greatly enhanced.

A. Vidicon Section

The vidicon section uses a standard electron beam which is focussed from an electron beam cathode filament and which is programmed to scan the silicon target. The scanning routine is provided by the PARC 1216 Multichannel Detector Controller which is programmed by our custom interfaced LSI-11 to scan a particular pattern.

The silicon target is made up of a microscopic array of photodiodes with a spacing between photodiodes of about eight microns. The scanning electron beam uniformly charges the surface of the diode array target, thus creating a depletion region between the p- and n-type silicon. Because the silicon target stores optical signals with excellent linearity, the scanning electron beam can read the signal from the target at a later time. Signal is stored on the target by the formation of electron-hole pairs referred to as target pairs. Target pairs may be generated by either direct electron bombardment or by absorption of photons.

Electron-hole pairs are formed as in all solid state devices by the excitation of an electron from the valence band into the conduction band. Once formed in the target diodes, the positively charged holes and the negatively charged electrons migrate to the appropriate regions of the diode. When the electron-hole pairs recombine, they cause a local depletion of the surface charge on the target. The OMA preamplifier measures the amount of charge required to refresh the target. The current required to refresh the target due to charge depletion is integrated for one channel period and is then converted into a useful signal for the OMA electronics. The charge sensitive preamplifier circuit is connected to a analog-to-digital converter which sends the signal for each channel in real-time to the computer through a 16-bit parallel interface.

B. SIT Intensification

Figure 1 shows the response of the SIT and ISIT detectors. The response is roughly 2-10% quantum efficiency for SIT detectors. The ISIT has a much better red and near IR response. THe addition of a UV scintillator coating on the fiber optic faceplate serves to extend the UV response of the detectors.

Figure 2a shows the electrostatic SIT detector in cross section. As in photomultiplier tubes (PMT), photons are image on an S-20 photocathode. The detection of photoelectrons that are formed is the essential consideration in intensifier design. The image intensification stage in this detector yields approximately

2000x amplification in target pair generation. This is accomplished by the acceleration of photoelectrons generated at the photocathode through approximately a 10 KV potential. However, because of other losses[16] associated with the intensifier design, the net improvement of the detector sensitivity is only about 200x. Direct electron bombardment results in useful signal amplification through the gain in kinetic energy provided by the high voltage acceleration.

The SIT intensifier design also allows one to gate the high voltage to the photocathode. The PARC Model 1211 High Voltage Pulse Generator is capable of gating the high voltage with 1 nsec accuracy. This allows one, in effect, to electronically shutter the OMA from between 40 nsec to several hundred milliseconds. Furthermore, the delay and pulse duration may be pre-programmed by our LSI-11 computer. The shuttering ratio for this detector can be as high as 10^4 and may be improved in pulsed laser applications with the use of a Pockel Cell (electro-optic) switch.

C. ISIT Intensification

The ISIT (intensified silicon intensifier) target detector employs a two stage photoelectron amplification design, seen in Figure 2b. It should be pointed out that the comparison of opto-electronic devices should be made in terms of photoelectron detection sensitivity. In the SIT, two photoelectrons generated from the S-20 photocathode are required to yield a single detector count. In the ISIT, this is improved so that statistically each photoelectron produces a single detector count. In addition, the ISIT uses an ERMA (extended red multi-alkali) photocathode which improves the red and near-IR response of the detector. See Figure 1.

Photoelectrons may be detected quite efficiently in photomultiplier tubes used as photon counters without worry about amplifier noise, since such detection schemes apply the time profile of the photoelectron detections as a necessary criterion for the generation of a detected count. However, photomultipliers must operate in real-time, whereas vidicon targets allow one to store the data for later readout. This advantage is exploited in cooled detector extended delay target integration techniques.

To detect photoelectrons, a single electron is accelerated by an electric field. The gain in the kinetic ene of the electron in turn produces a very large gain in the number of target pairs on the target, which is then measured in terms of local charge depletion. However, the ISIT (as seen in Figure 2b) differs from the SIT since a P-2Ø phosphor acts to provide photon multiplication to the S-2Ø photocathode of the SIT stage. This serves to produce suitable gain such that single photoelectrons may be counted.

There are several disadvantages associated with ISIT detectors, however. Besides the added expense associated with these two stage intensifiers, they are not easily cooled for long term target integration. The ISIT does not handle cooling very well because of problems associated with the very long persistance of the P-2Ø phosphor at low temperatures.

D. Other Intensifier Designs

The inverting electrostatic intensifier (SIT) is widely used because of its stability against stray electric and magnetic fields, as well as low cost. However, because of the curvature of the photocathode, a certain amount of distortion is introduced. Furthermore, the use of the glass fiber optic faceplate cuts off its UV and IR sensitivity.

The magnetic intensifier employs both electric and magnetic fields to image the photoelectrons directly onto a phosphor screen without image inversion. However, this design does requires very stable electric and magnetic fields and therefore, costly power supplies.

Another intensifier utilizes extremely large electric fields to focus the electrons for very short distances. This intensifier is of a very simple design and is referred to as the proximity focus intensifier. It also requires very stable power supplies.

The detection of a single photoelectron generated at the photocathode can be done in other ways besides electron acceleration to form greater numbers of target pairs. One may also design intensifiers to provide electron multiplication, much in the same way that a dynode cascade architecture is designed in photomultiplier tubes.

An important intensifier technology which employs electron multiplication is the microchannel plate intensifier. The honeycomb design allow electrons to propogate down these narrow channels. Successive collisions allow for a great deal of electron gain. Although these devices provide significant gain, they do introduce some loss in resolution because of their physical dimensions and they tend to be very susceptible to amplification of noise. Furthermore, because of the high gain associated with electron multiplication, attachments of microchannel plate intensifiers on devices such as reticons, result in high susceptibility to heavy wear and damage. Consequently, frequent replacement of large diode arrays can be very expensive. Microchannel plate intensifiers, because of their freedom from lag, do however, result in excellent performance in single shot and gated experiments.

III. LOW LIGHT LEVEL SIGNAL INTEGRATION

One would like to compare the performance of cooled vidicon (SIT) detectors with other kinds of photodetectors, in particular single-photon counting schemes for photon fluxes of less than about 1 photon/sec-channel.

Photon counting employs the use of a single channel photodetector which discriminates pulses on the basis of its time profile. This system results in the rejection of non-photon correlation functions and therefore such systems do not suffer from amplifier noise. However, photon counting is generally limited to single channel detection and thus does not offer the multiple channel capabilities of an optical multichannel analyzer.

I will investigate the sensitivity of the OMA vidicon under optimal conditions by comparing it with other photon counting systems. I would like to point out that such comparisons of the detector sensitivity depend on a number of factors and are still a topic of considerable controversy, in particular with respect to other diode array scanners[18], reticon devices[19], and CCD array packages[20]. It is particularly dangerous to utilize these values for specification purposes for vidicon technology, since the user is given quite a bit of freedom with which to optimize the readout efficiency of his detector for specific applications. Furthermore, the emphasis here is on techniques and trends rather than on absolute values which may not be routinely achievable in all situations.

A. Target Integration

For very low light levels, it is advantageous to allow the signal to acquire on the target before electronic readout because of the amplifier noise generated for each scan. Therefore, instead of reading it out continuously and averaging in computer memory, one allows the signal to integrate on the target. A charge sensitive preamplifier circuit measures the amount of current required to recharge the SIT target as the electron beam scans each pixel area or channel. Because this is essentially an analog measurement, this preamplifier circuit suffers from amplifier noise. The amplifier noise is roughly one count rms/scan.

The total amount of photoelectron generated noise goes as the square root of the number of photoelectrons detected. The total noise (in counts) is given as :

$$N_t = (N_r^2 + N_s^2)^{1/2}$$

where N_r is the noise contribution associated with the electronic readout and

N_s is the noise due to the signal.

It is easy to see that since the contribution due to readout can be a large fraction of the total noise for extremely low level light signals, it is advantageous to reduce the actual number of readout scans such that the photoelectron statistics will dominate the S/N performance.

It is for this reason that the technique of extended delay target integration was developed. Improvements in the S/N are made by allowing the signal to acquire on the target so as to reduce the total number of readout scans and to bring the signal well above the detection limit threshold.

Electron-hole pairs generated on the target migrate to the appropriately charged area of the target. At room temperature, the charge stored on the target has a lifetime of several hundred milliseconds after which time capacitive leakage of the charge occurs. Normally, since the vidicon scanning beam reads out the signal within 70 msec for single track scanning, this does not result in significant signal losses due to this charge leakage. However, when one performs extended delay target integration for much longer periods of time, one encounters severe data loss.

By cooling of the detector to dry ice temperatures (-60 ^{o}C), one increases the time to as much as several hours for which the signal remains. This allows one to collect signal on the target for extremely long periods of time and to read it off after significant signal has acquired on the target. It is found that we achieve S/N ratios greater than 5:1 only after target integration for times such that the electronics detect at least 300 counts/channel-scan.

B. Dark Current

For extremely low light signals, one has to consider the problem associated with thermal dark current. Dark current arises from the Boltzmann distribution of electronic energy states about the Si band gap. These thermally generated electron-hole pairs then manifest themselves macroscopically as charge leakage from the target surface. For example, in intrinsic silicon the band gap is about 1.1 eV. If one looks at the Boltzmann distribution at various temperatures, one finds that the cooling of the detector from room temperature to -60° C can yield an attenuation in excess of 10^{6}. Since the dark current is an intrinsic property of the detector, it is sometimes difficult to assess the absolute number of thermally generated detector counts, apart from other possible sources of A/D counts.

In Figure 3, the dark current thermal profile across the detector from channels 0-500 before and after background subtraction is seen for the detector at room temperature and when it is cooled. One should note that the baseline is not flat[21]; this may be attributed to the actual thermal fall off at the edges. At -60° C, an estimate of the dark current is less than 2 counts/sec based on Figure 3d, since the # counts rms/channel after subtraction is approximately 10.

One should note here that provided the temperature of the SIT detector is constant and that suitable target preparation techniques are used, a background collection of the detector (including dark current) can be stored in digital form in the computer memory and will not change substantially during the course of an experiment. It is for this reason that the actual dark current does not hurt you too badly, since it is normally subtracted out. However, for extremely low level light signal, dark current can potentially hurt you in the following way. Since it is, in fact, a real signal source, it also has a noise associated with it which goes as the square root of the number of thermally generated counts. By lowering the dark current through cooling, one hopes that thermally generated counts will be substantially less than the photoelectron counts so that the noise associated with the dark current will have a muchless detrimental effect.

The normal way that one acquires good spectra is to repetitively signal average until a reasonable S/N ratio is obtained. Since the signal goes up linearly with collection time and the noise goes up only as the square root, one hopes to eventually reach a suitable S/N ratio. However, there are practical limits to signal averaging and target integration capabilities of the SIT detector. For fluxes of about 0.3 photoelectrons/second-channel, we have been able to achieve S/N ratios from extended delay target integration of 10:1 by cooling the detector to -60° C and integrating signal for approximately 3 hours.

Figure 4 shows the general specifications to be expected upon cooling of the detector. Depending on the time for which signal integration takes place, one can effectively improve their S/N ratio. It should be pointed out that cooling to eliminate dark current has a lower limit, since the manufacturer warns against the possibility of tube damage due to differential contraction for temperatures much below that of liquid nitrogen.

Cooling of the detector was achieved by converting the PARC 1212 Dry Ice Cooled Housing for the OMA to a closed system liquid ethanol refrigeration unit. A freon based two stage cooling tip from F.T.S. Corp.[22] was built into the dry ice resevoir. Two liters of ethanol was used in the cooling resevoir for the SIT detector and equilibration was generally achieved after about a five hour waiting period. The refrigeration unit was preferable to the dry ice system since it was difficult to replenish the dry ice resevoir without disturbing the optical alignment. It should be noted that during signal integration, the liquid cooler was turned off since the compressor tended to introduce vibrations into the detector. A nitrogen purge, as well as a dessicant, were used to prevent condensation on the detector, in particular on the diode array target.

C. Target Preparation and Readout Optimization

In the OMA 2 system, the Multichannel Detector Controller is fully programmable. This allows one to scan the region(s) of interest at various dwell speeds, as well as to optimize the detector readout capability. For extended delay target integration, the user interacts with the OMA from the keyboard console. Besides the usual scan parameters specifying a scan program, the user is queried as to the length of time for which he wishes to allow the light to integrate on the target, the number of readout scans, and the number of times he would like to repeat the target integration.

Vidicon detectors suffer from a phenomenon known as lag. Because of lag, silicon target pairs cannot be read off completely in a single reading scan. At low temperatures, this electronic time constant can be quite long. One must therefore judiciously choose the number of readout scans such that most of the signal is read off without introducing too much noise from the amplifier circuitry. At low temperatures, we have found that from 10-50 scans are optimal for extremely weak signals.

Since the signal is stored on the target for a finite time, one often would like to repeat the target integration process several times to get the averaging effect one obtains from continuous scanning. This also allows the computer to completely run the experiment for very long periods.

For extended delay target integration, the target is first illuminated by flashing an LED to uniformly discharge the detector target for optimal reading efficiency. Fifteen preparatory frames are used to read off the saturated target from the LED flash.

At this point, the target is allowed to integrate the light. The filament to the scanning electron beam is turned off in order to reduce the possibility of it being a source of stray light to the vidicon target. It is then turned back on approximately 20 seconds before readout.

The detector target is then scanned at a higher cathode voltage (+0.5 V), in order to improve the readout efficiency and to therefore reduce the effects of lag. The programmed op codes are sent in real-time for target preparation and are double latched so that the scanning process changes are assuredly frame synchronized. The LSI-11 computer thus provides the timing for the experiment as well as performs a number of housekeeping chores, besides providing the real-time data acquisition and data manipulation routines.

D. Experimental: High Resolution UV/VIS Spectroscopy

The use of the OMA for high resolution UV/VIS spectroscopy was the primary aim of the development of extended delay target integration methods. The measurement of temperature dependent triplet state exciton lineshapes in 1,2,4,5-tetrachlorobenzene (TCB) was the goal of our research.[23] Since the phosphorescence linewidths are very narrow (3-10 cm^{-1} FWHM), it was critical that the detection of very small frequency shifts and widths as a function of temperature be measured with very high resolution. Because of the reproducibility problems in the scanning of the spectrometer in a conventional single channel PMT experiment, the use of a multichannel detector was very attractive. With an OMA, we would be able to collect the spectroscopic lineshapes without the necessity to mechanically scan the frequency region of interest. To acquire the necessary dispersion (.05 cm^{-1}/channel) required the use of a 2 meter Jarrel-Ash spectrometer in second order, in addition to using a 5x magnification macro camera lens at the exit port.

The experimental set-up is seen in Figure 5. A single crystal of 1,2,4,5-TCB is immersed in a liquid helium cryostat between 4.2-50 Kelvins. A 75 watt high pressure Hg arc lamp is used as an excitation source in the UV region. Triplet state phosphorescence at 3750 Å is then focussed into the spectrometer and the lineshape is imaged onto the SIT detector with a macro lens. Since the amount of phosphorescence intensity is very low, alignment is aided with a He-Ne laser and/or an Fe hollow cathode lamp used for calibration purposes. In this particular set-up, a dedicated LSI-11 satellite may be used for data collection by networking (REMOTE-11) into an LSI-11 host computer. A multichannel analyzer (MCA)[24] can also be used for real-time spectrum integration viewing. Temperatures can be controlled by the host computer through a calibrated Carbon resistance thermometer connected to a precision digital multimeter[25], which is interfaced to the host computer.

Figure 6 shows the exciton fundamental in TCB using extended delay techniques with target integration for six minutes. The first plot shows the signal collected with the concommittant dark current while the second shows the spectrum after digital background subtraction. One should not in Figure 6a that the dark current/background is considerably greater than the signal itself, i.e. the signal sits on a very large DC offset. One quantitatively performs background subtraction and baseline renormalization to restore the AC features of the spectrum. The photoelectron flux corresponds to less than 40 counts/sec-channel. One should also note that features of the thermal background profile are most pronounced near the edges. After background subtraction, these features are removed. See Figure 6b. The rising and falling tails of the lineshape are very important in our theoretical models and are not artifacts of the signal integration process.

Finally, one cannot over emphasize the importance of detector temperature stability for cooling. Before reaching steady-state, background subtraction and renormalization are almost useless. There are other advantages for the use of extended delay techniques over that of silver halide photographic plates. Besides the ability to collect the data quickly without photographic processing, the signal processing capabilities of a computer are quite significant. In addition, the OMA has an extremely linear response to photons which results in extremely good lineshape data. On the other hand, silver halide photographic response is logarithmic and therefore requires careful calibration procedures.

IV. TRANSIENT PULSE SIGNAL CAPTURE

The OMA is ideally suited for transient pulse signal capture becuase of its multiple channel storage capabilities. This is considerably more advantageous than fast multiplexing electronics (> several hundred nsec) since one effectively stores the data for later readout.

Earlier, the mechanisms by which photoelectrons may be formed to create images which may then be digitized for computer data processing were described. These mechanisms still apply in transient systems; however, the techniques involved for optimizing signal processing are necessarily different because of the pulsed nature of the signal.

There has been a great deal of interest in the possibilities of gating the detector for time-resolved spectroscopic applications, but these in general are more relevent to the observation of kinetic phenomenon with microsecond decay life times.

We would like to present techniques which have been successful for the data capture of subnanosecond transient phenomenon generated from a pulsed ND:glass picosecond laser. In addition, we will show an example where we use the 2-D nature of the photodetector for multiple tracks data acquisition.

A. Pulse Synchronization- EXPERIMENTAL TRIGGER START

In a transient pulse experiment, it is necessary to synchronize the vidicon readout with the light pulse for greatest readout efficiency. The advantage of reading out the detector only when there is signal present is obvious. In a low light level CW experiment, target pairs must build up on the SIT detector, whereas in the case of a pulsed experiment, peak light power is very great, but its duration is quite short.

In a synchronous experiment, the computer generates a trigger which gates both the laser as well as prompting the OMA to begin readout scanning. Depending on the experimental trigger delay requirements, a number of different alternatives are available for synchrnonizing the OMA readout electronics.

In the experiment, the computer prepares the OMA target, after which time the 1216 Multichannel Detector Controller sends a +5V EXPERIMENT START pulse to the laser. Since the laser propogation time is well below 100 microseconds (actually 50-200 nsec), the laser flashes before readout occurs on any of the central 500 channels of the target. The vidicon detector then performs about 10-15 readout scans to efficiently collect all the stored signal.

If the propogation delay time for the trigger was not performed through hardware at high speeds (> 100 microseconds, i.e. such as manually), one might expect that the light pulse hits the target during the middle of a readout frame. Because of surface charge leakage and other effects, one may find that this may cause a non-uniform spectrum to occur on the left and right of the channel in question. Successive readouts tend to reduce this effect, which seems to be a more serious problem with the OMA 1.

One should also make sure that the pulse repetition rate does not exceed the readout time for the detector. For example, for a 500 channel frame at 60 microseconds/channel using 10 readout frames requires 300 msec. This means that approximately 3 Hz would be the highest repetition rate possible under these conditions.

There are many alternative ways to obtain pulse synchronization. The 1216 Multichannel Detector Controller also provids for programmable TRIGGER 1 and TRIGGER 2 outputs, as well as an EXTERNAL EVENT input (also connected to interface bus (read/write)). These alternatives can be programmed and controlled by our LSI-11 directly.

B. Signal Capture and Readout

The stored charge on the silicon target has an image latency of several hundred milliseconds at room temperature. Because the detector suffers from lag, the SIT Detector requires more than a single scan to effectively read off the total charge. One must be reassured, however, that provided that the readout is optimized to read the off the charge completely that the signal response will be linear (+2%). THe dynamic range is well over $1x10^4$. For optimal results, one should attenuate the light if necessary by using neutral density filters.

Generally ten to fifteen scans is optimal at room temperature. However, there has always been some question as to whether cooling of the detector will improve the S/N in a pulsed application. Our belief is that in general for spectroscopic applications that it is not likely to help at all, even though the dark current will be reduced. Since our light pulse is so intense, the thermally generated dark current is a negligible fraction of the total signal, especially since the readout is tailored to less than a few milliseconds.

However, for two dimensional imaging where one uses 500 tracks, the total readout time is multiplied by 500. The effect of this is that the readout times for a single frame scan far exceeds the storage retention time of the silicon detector at room temperature. By cooling, one reduces the dark current, but more importantly, one allows the storage of the charge image until it can be completely read off. We would like to point out that a 500x500 scan program requires over 240 K words of memory in single precision and furthermore takes many seconds to read it off just once.

C. Experimental: 2-D Mode Detection of Picosecond Laser Generated Raman Spectra

This research effort is aimed at understanding the nature of energy transfer in condensed phases using picosecond laser spectroscopy.[26] A mode locked Nd:glass laser (pulse width ~ 5 psec) is used to study excited state vibrational relaxation by measuring lineshapes from the Stokes Stimulated Raman Scattering process.

The laser pulse repetition rate is once every 45 seconds and the experiment is almost completely automated with microprocessor control. Once it is set up, the user interacts with the data acquisition system only to save the data on mass storage or to discontinue the experiment. In this experiment, a single TEM OO pulse at 10,600 Å is picked from a mode-locked pulse train using a Pockel cell. See Figure 7.

The laser pulse is frequency doubled using a KDP crystal and is then beam split into two differnt optical paths. In a classic excite and probe technique the liquid in a 10 cm^{-1} Raman cell is illuminated. The Stokes Stimulated Raman emissions are labelled as follows. First, they are delayed in time with respect to one another through the use of a nanosecond optical delay line. Secondly, they are tagged with different polarizations. It is this difference in polarization which is used to spatially resolve the excitation from the probe stokes lines. The pulses are resolved spatially through Glan-Thompson polarizers which image the light into either the top or bottom halves of the entrance slit to the monochromator.

With the use of the 2-D OMA one is able to collect the spectra by subdividing the vertical channel elements into two sections and programming for two tracks. See Figure 8. It is by measuring the differences in the lineshapes that one obtains information about the dynamics of the vibrational relaxation processes.

The user is presented with the spectrum immediately after signal processing is completed and is given the opportunity to write to the disk, save the data in buffer memory, or to stop the laser data acquisition and manipulate the data.

With this system, our research group has been able to study many different liquids and to make some predictions about vibrational dephasing times and their relationships to other macroscopic properties of these solvents.

D. Comments

It is clear that if one understand the physics behind the OMA as a detector that one would best be able to use it to the greatest advantage. Furthermore, the use of 2-D mode for multiple tracks allows one, in effect, to monitor more than one optical process in an experiment. This represents a great advantage over similar 1-D array detectors which offer far less programmability and therefore versatility.

In many cases, the use of the OMA as a 2-D imaging device represents a low cost means of image processing by using the techniques described in this paper.

The OMA 2 can also be used in random mode as well to signal average single pixels or regions of the target. This would be a ideal application for LEED intensity analysis. It is clear that the OMA properly used can be implemented in a wide variety of experimental situations.

V. CONCLUSION

It is clear that the direction for applications of these 2-D vidicon detectors of this type will be in the area of 1.) time-resolved spectroscopy or time-domain imaging and 2.) full 2-D imaging for low-light level signals. In the area of time-resolved spectroscopy, the use of a HV pulse generator unit[27], optionally in conjunction with a Pockel cell switch in high power pulsed laser applications[8], will be an extremely important tool for electronic shuttering from a few nanoseconds to several milliseconds.

The use of the OMA or similar 2-D imaging device will play an important role in high-speed monitoring of manufacturing processes in a number of diverse industries. In this area, considerable attention has been given also towards the use of these devices with appropriate spectral converters to image X-rays.[2] Finally, as progress in electronic imaging becomes more and more advanced, the degree of sophistication in data processing will undoubtedly grow. Developments in the areas of image enhancement and pattern recognition will further the use of these two dimensional imaging systems. Certainly, in the medical area, the use of CAT scanners to provide X-ray sectioning to reconstruct 3-D images has proven to be a very valuable medical diagnostic tool.

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14. J. L. Weber & P. W. Roehrenbeck, Optical Spectra, pp. 58-62, March 1979.
15. C. F. Freeman, SPIE Proceedings 42, 3, (1973).
16. Photoelectron losses can occur at a number of places in the intensifier stage. The fiber optic faceplate and UV scintillator coating introduce losses. Spurious reflections may occur; this often leads to a phenonmenon

known as halation.

17. See Application Notes, for example from Princeton Applied Research Corporation, Princeton, N.J., or Pacific Precision Instruments (PC-1), Concord, CA.
18. For example from Tracor Northern, DARSS, Middleton, WI.
19. For example from Reticon, subsidiary of E G&G Company, Sunnyvale, CA.
20. For example, Fairchild Semiconductor, Mountain View, California.
21. The detector is actually a 512x512 array. However, because of edge distortions of the target by virtue of the curvature of the photocathode in the design of the electrostatic intensifier, only 500x500 is actually used. In addition, freedom from distortion, i.e. uniformity is achieved principally in the central region of the target so that normal spectroscopic lineshape information is obtained by using 500 channels and using a central channel height of 250 channels.
22. F.T.S. Model LC-80 Liquid Cooler, Stoneridge, N.Y.
23. J. L. Chao, Ph.D. thesis, University of California, Berkeley, 1980.
24. Tracor Northern, Model NS-575 Signal Averager.
25. Data Precision Model #DM 3500, Wakefield, Massachusetts.
26. C. B. Harris, H. Auweter, S. M. George, Phys. Rev. Lett. 44, 737, 1980.
27. PARC Model 1211 High Voltage Pulse Generator, Princeton, N.J. The delay and pulse duration are programmable through the OMA 2 1216 Multichannel Detector Controller.

*Note: Figures reproduced with permission from Princeton Applied Research Corporation.

†——Present address: IBM Instruments, Inc., 3000 Westchester Ave., White Plains, New York.

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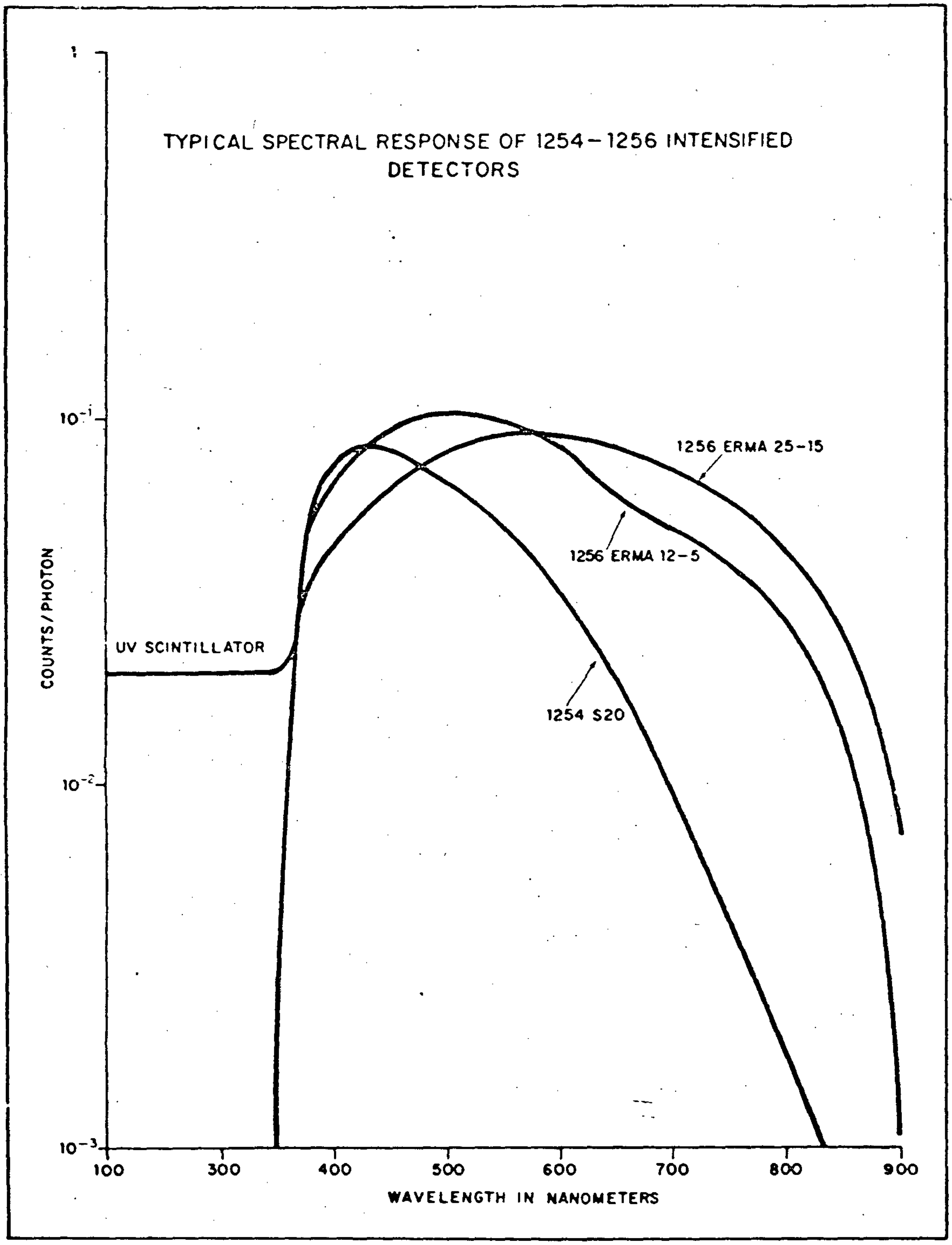


Figure [illegible]-1 : The S-2Ø response of the 1254 SIT w/ and w/o UV scintillator is seen. Two ERMA (extended red multi-alkali) detector response curves of the ISIT design are shown.

Cross-section of SIT (silicon intensified target)

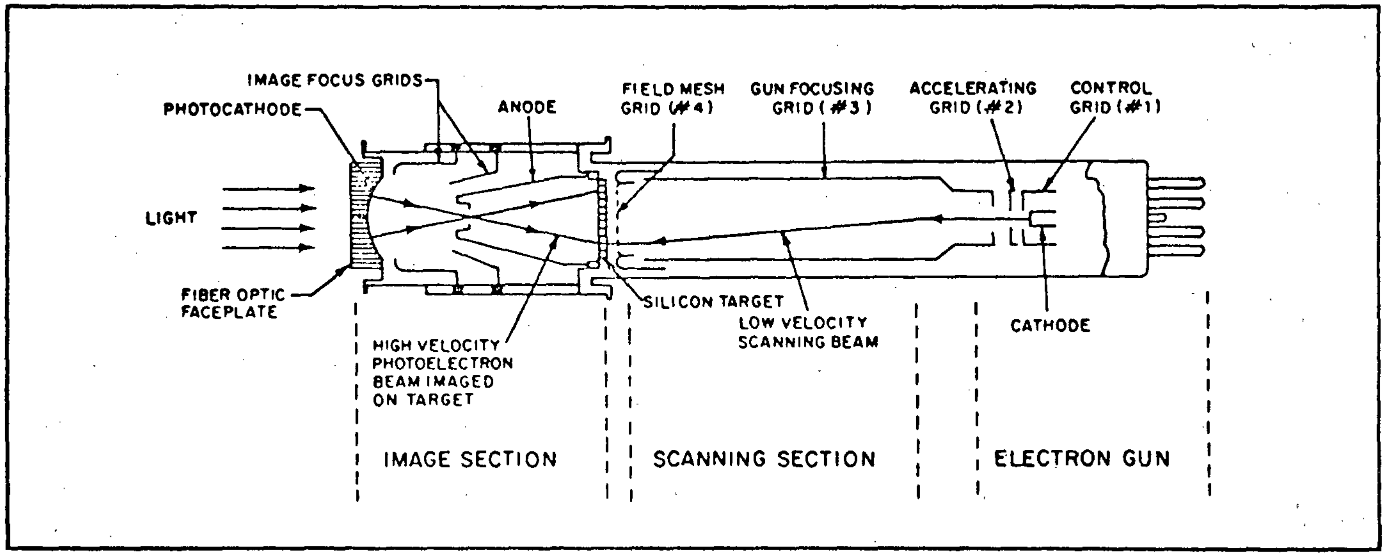
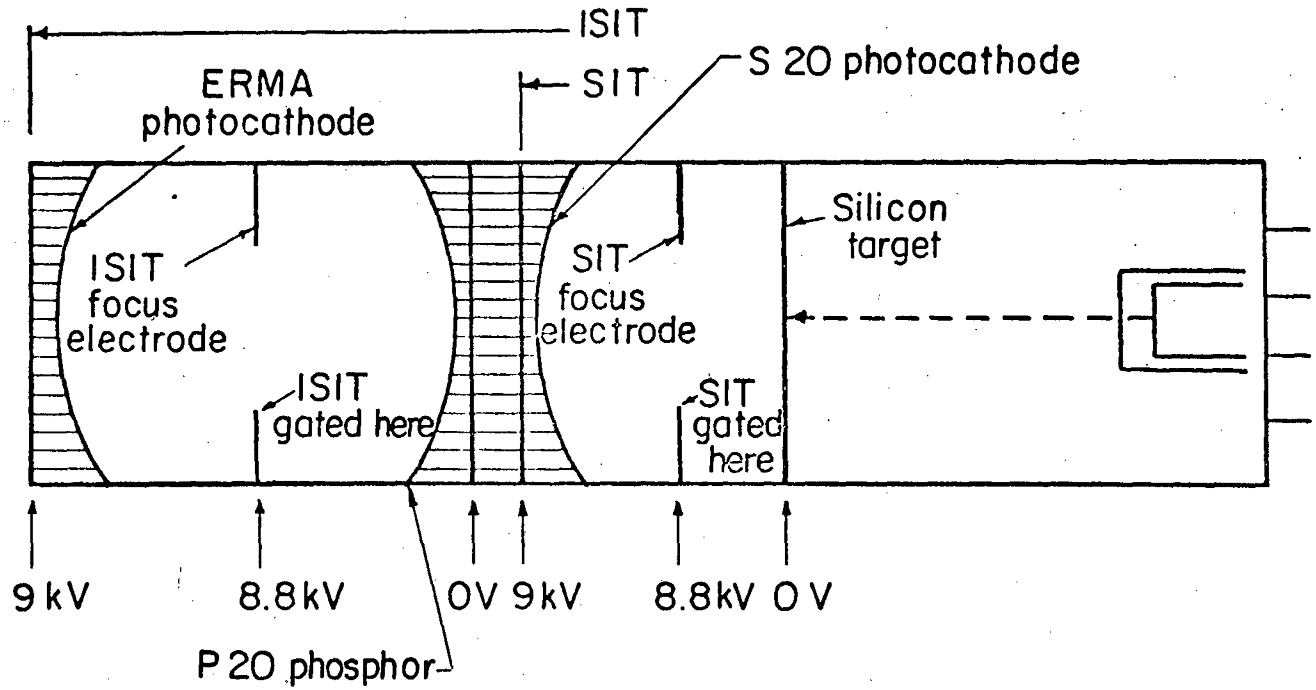


Figure 2a

Cross-section of ISIT Detector



XBL 804-5013

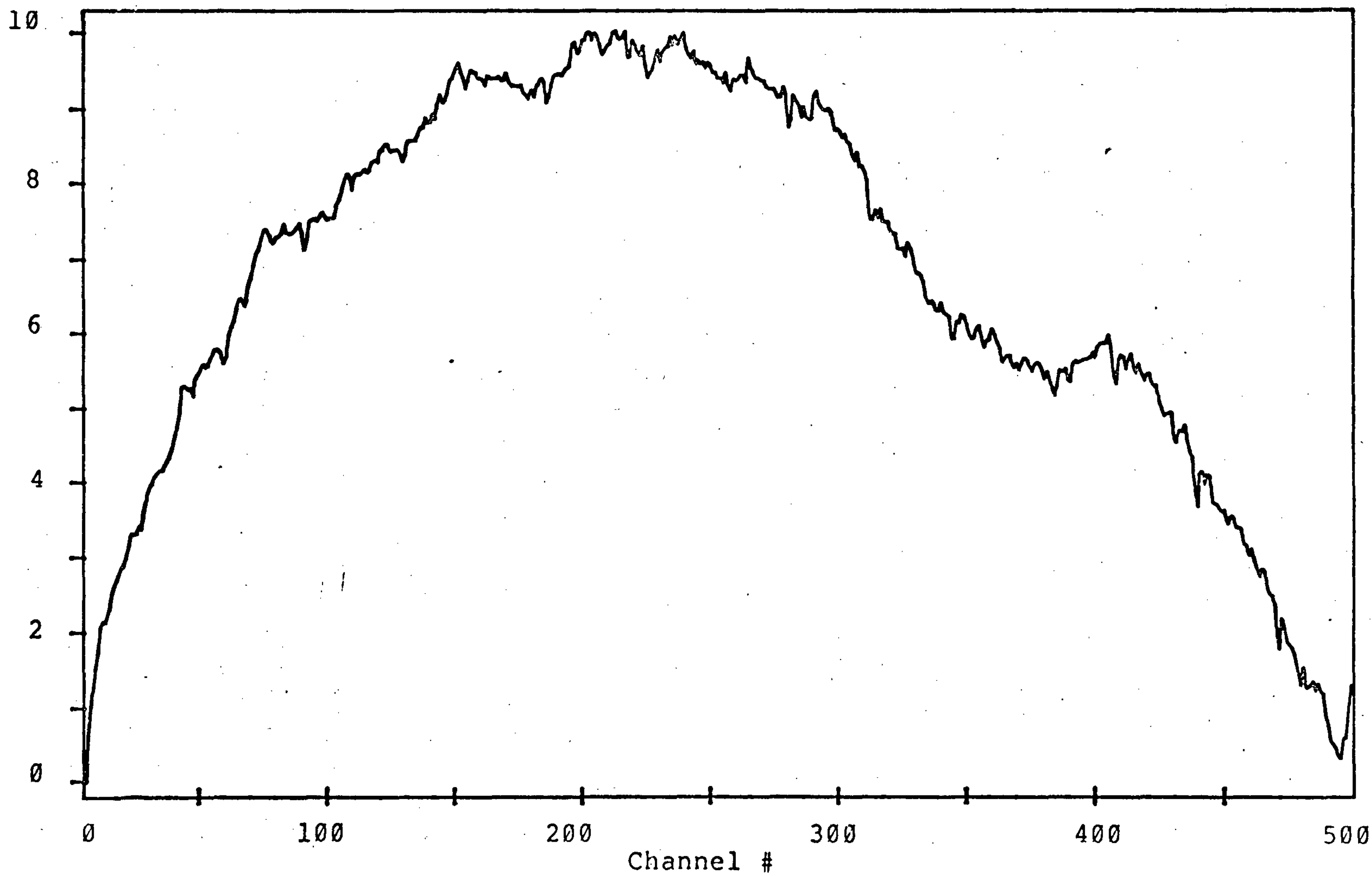
Figure [redacted]-2b

Figure [illegible]-2a : The detection of photoelectrons generated at the photocathode is the primary concern of intensifier design. The image intensifier section provides electron acceleration to produce a linear response of target pairs generated at the silicon target. A slow scanning electron beam reads off the resulting charge loss stored on the target.

Figure [illegible]-2b : A doubly intensified ISIT results in a statistical response of 1 count/photoelectron. A P-2Ø phosphor is used after the first electrostatically intensified section of the detector.

Room Temperature Thermal Profile of SIT Detector

Figure [redacted]-3a



max = 31,251 min = 25,035

Room Temperature Noise After Background Subtraction

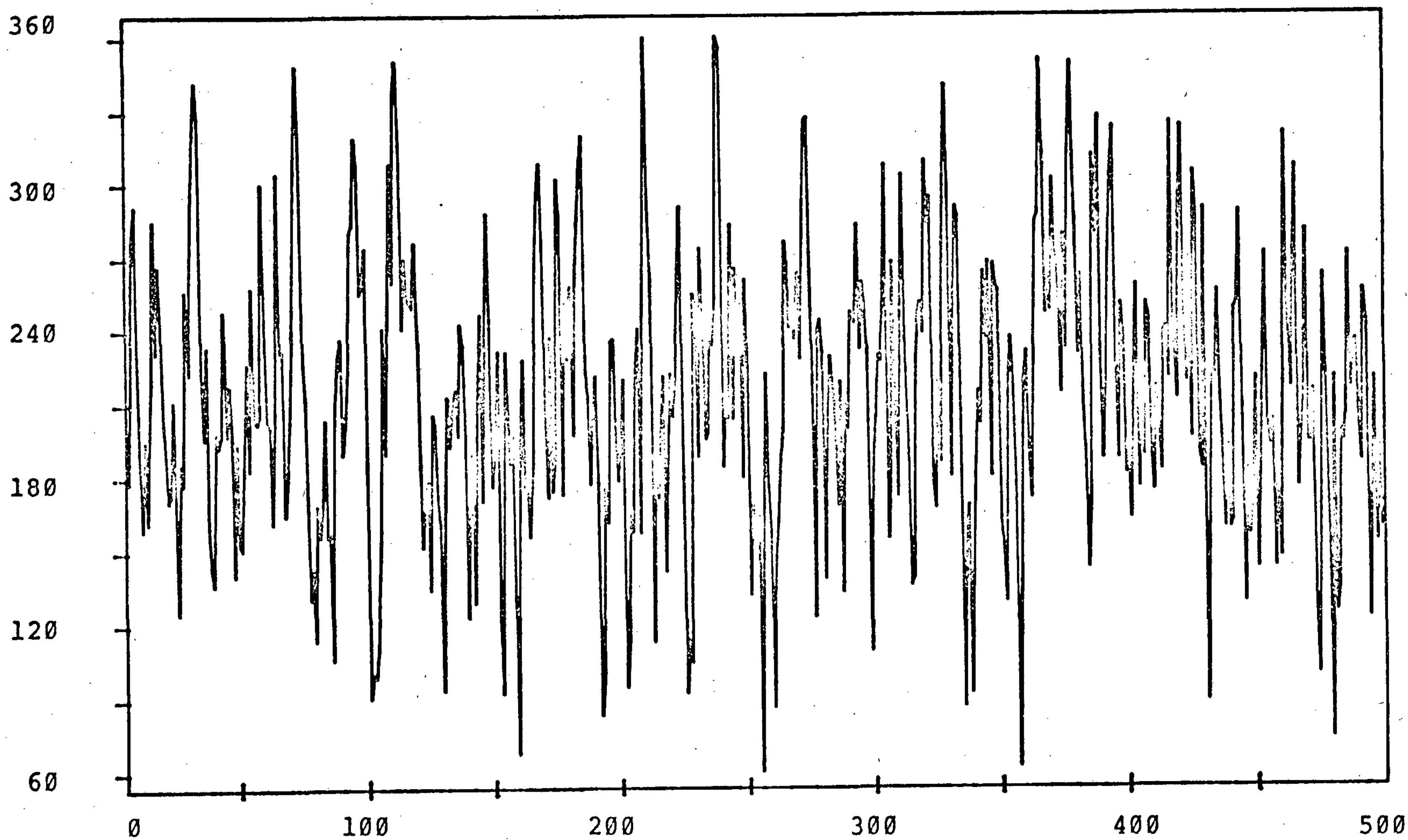


Figure 3b

Maximum # counts = 358

SIT Detector Thermal Profile at -60° C

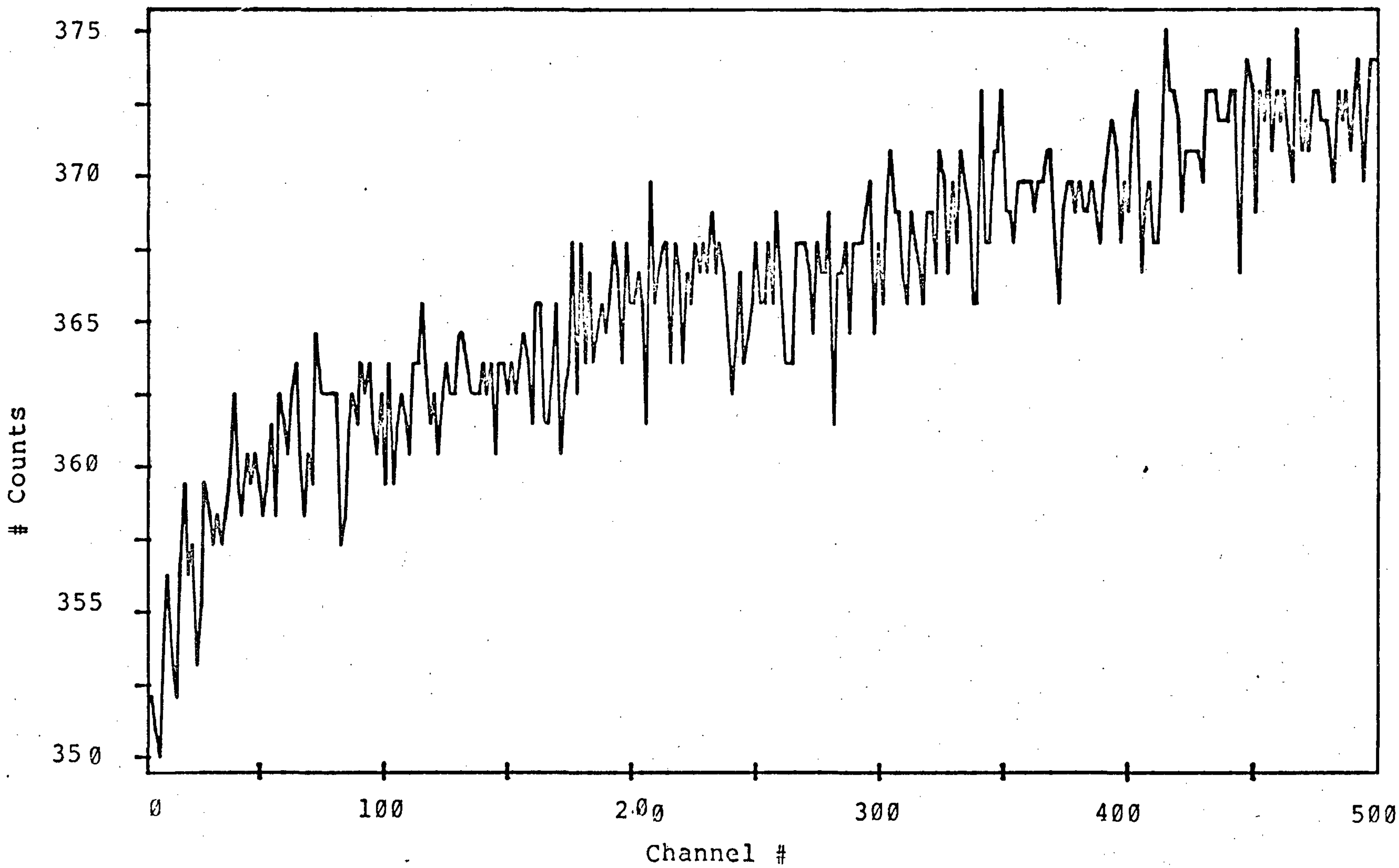


Figure [illegible]-3c

SIT Detector Noise After Background Subtraction at -60 °C

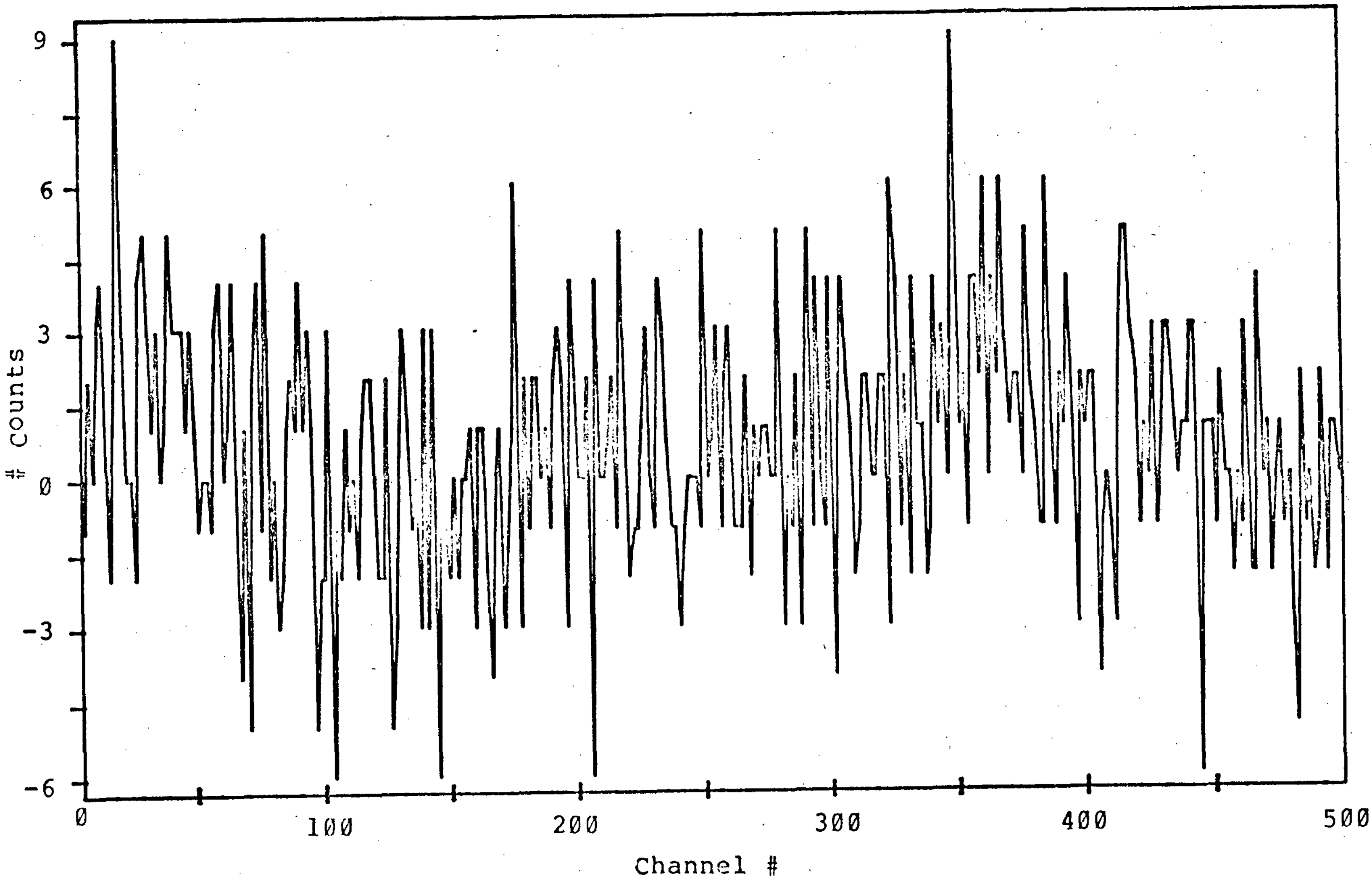


Figure 3d

Figure 3 Captions

a.) Room Temperature Thermal Profile of SIT Detector

b.) Room Temperature Noise After Background Subtraction

c.) SIT Detector Thermal Profile at -60 °C

d.) SIT Detector Noise After Background Subtraction

From a.) and b.) one can estimate the dark current contribution by taking the r.m.s. # background counts (~200 counts/channel). By squaring this figure one gets approximately 4.0×10^4 counts. Since this was collected over 50 msec, we get roughly 8×10^5 thermally generated counts/sec at room temperature.

Similarly, for cooled detector target integration one sees that roughly the number of rms counts is 10 counts/channel. This means that 100 real thermal counts are generated for the 45 seconds target integration time. This means that one can estimate the dark current at about 2 counts/sec at -60 °C, which represents an attenuation of about 10^5. This is just an order of magnitude calculation and ignores other sources of noise or stray light.

Signal-to-Noise Ratios for Various Photon Fluxes and Extended Delay Target Integration Times

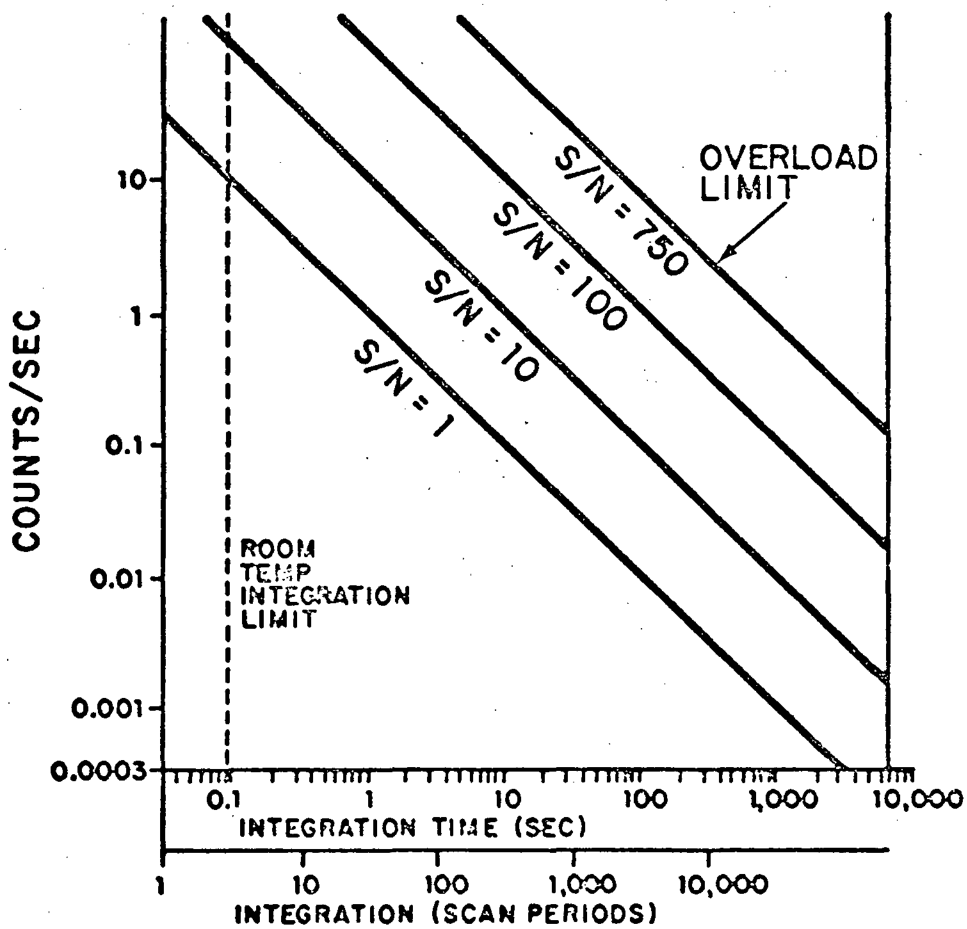


Figure -4 : Cooling allows one to go to extremely long signal integration times to achieve high S/N ratios.

High Resolution Phosphorescence Emmission Experimental Set-up

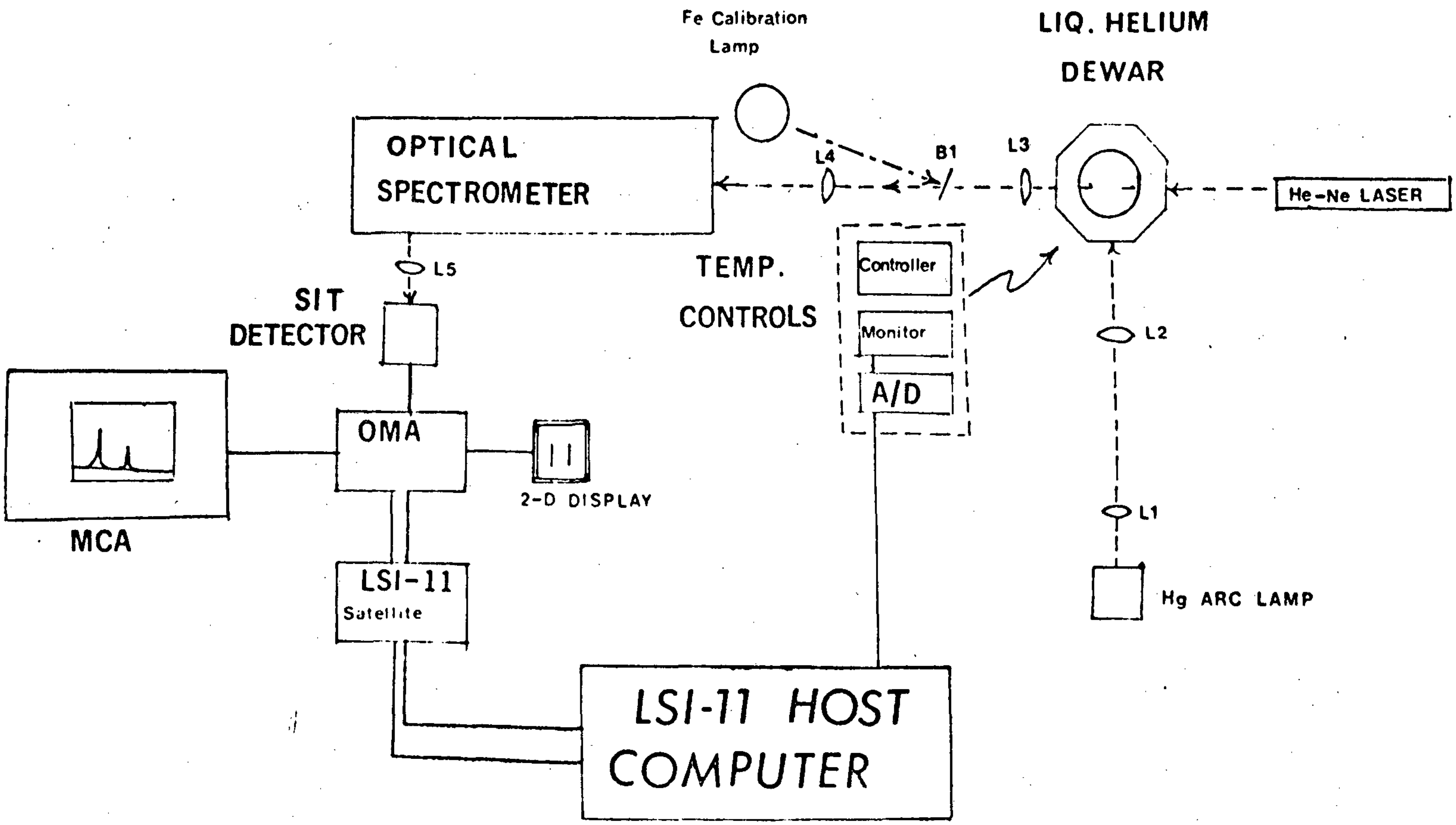


Figure 5 : The OMA is part of the experimental set-up which includes cryogenic handling equipment. Computers automate the experimentation providing feedback as well as data acquisition for long target integration times.

XBL 805-9505

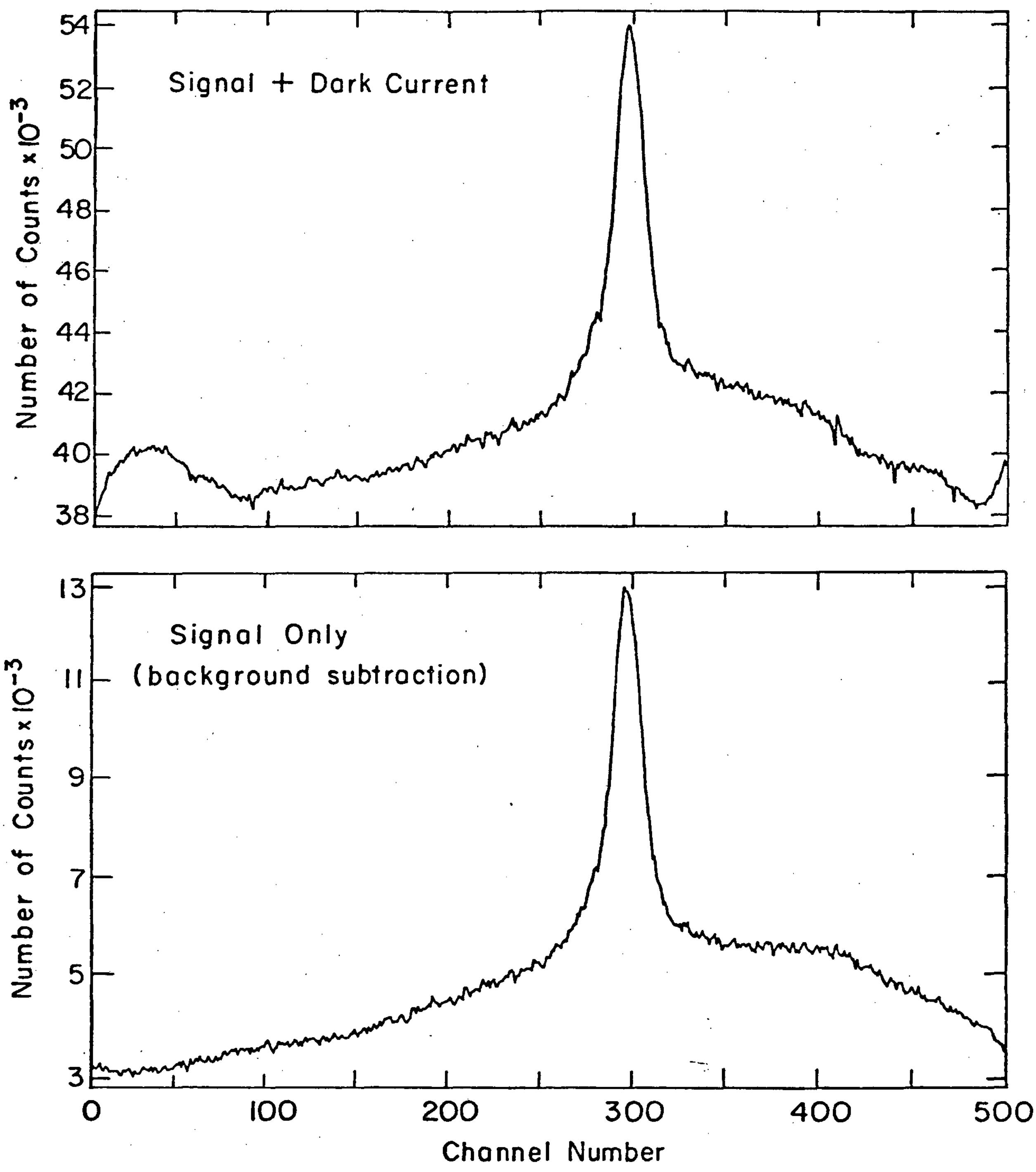


Figure -6 : 1,2,4,5-Tetrachlorobenzene Exciton Phosphorescence a.) Before and b.) After Background Subtraction Using Extended Delay Target Integration Techniques.

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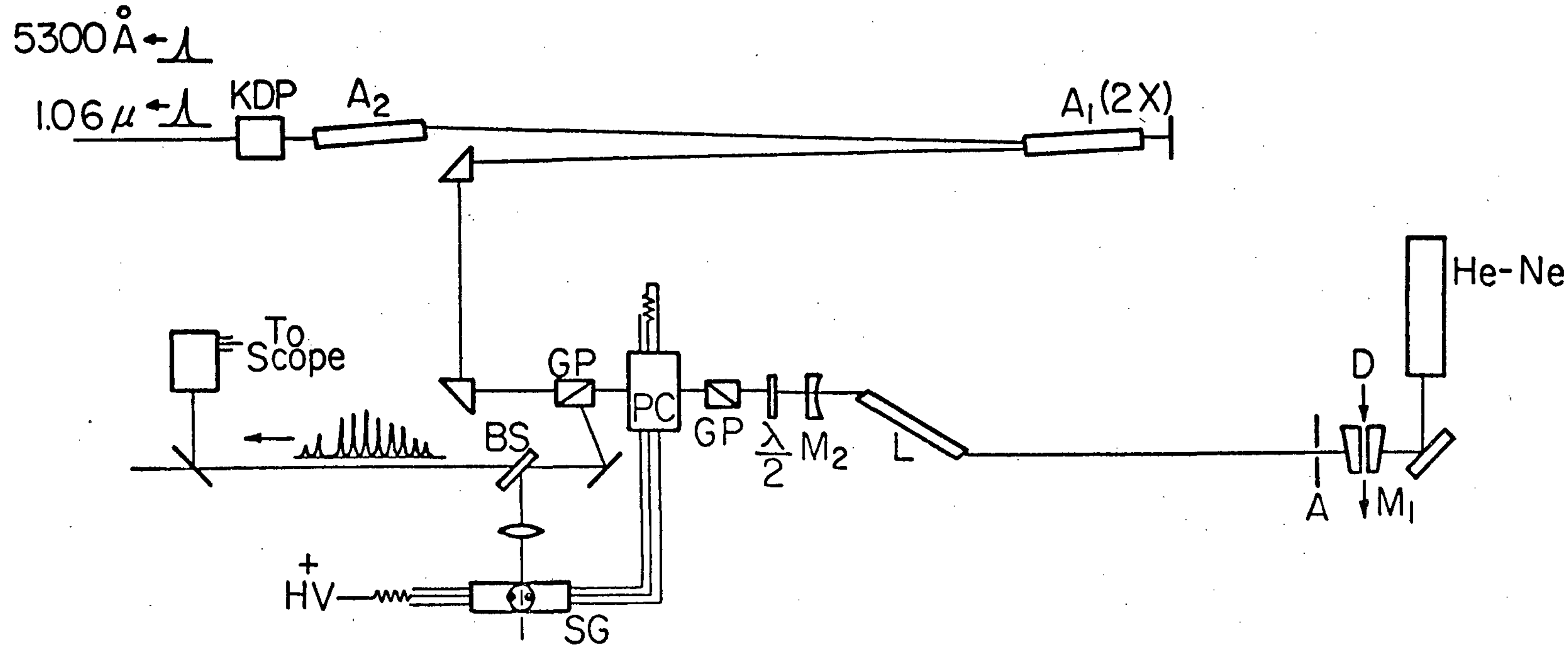
Thermal background features are removed using background subtraction.

MODE LOCKED Nd-GLASS LASER SYSTEM



XBL 7612-7942

Figure 7 : Laser set-up shows Pockel Cell switch for extracting a single picosecond (~5 psec FWHM) pulse from a mode-locked train.

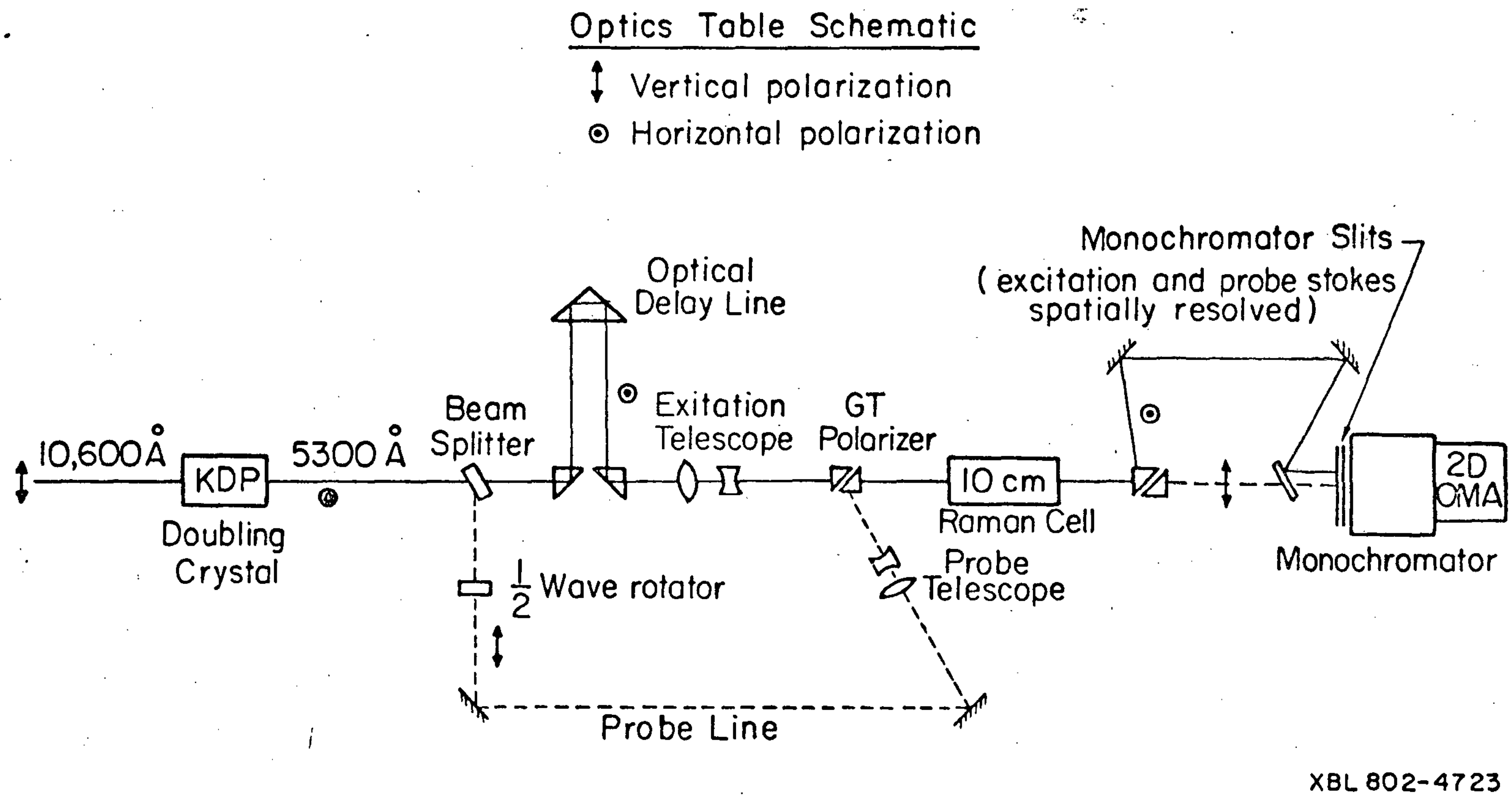
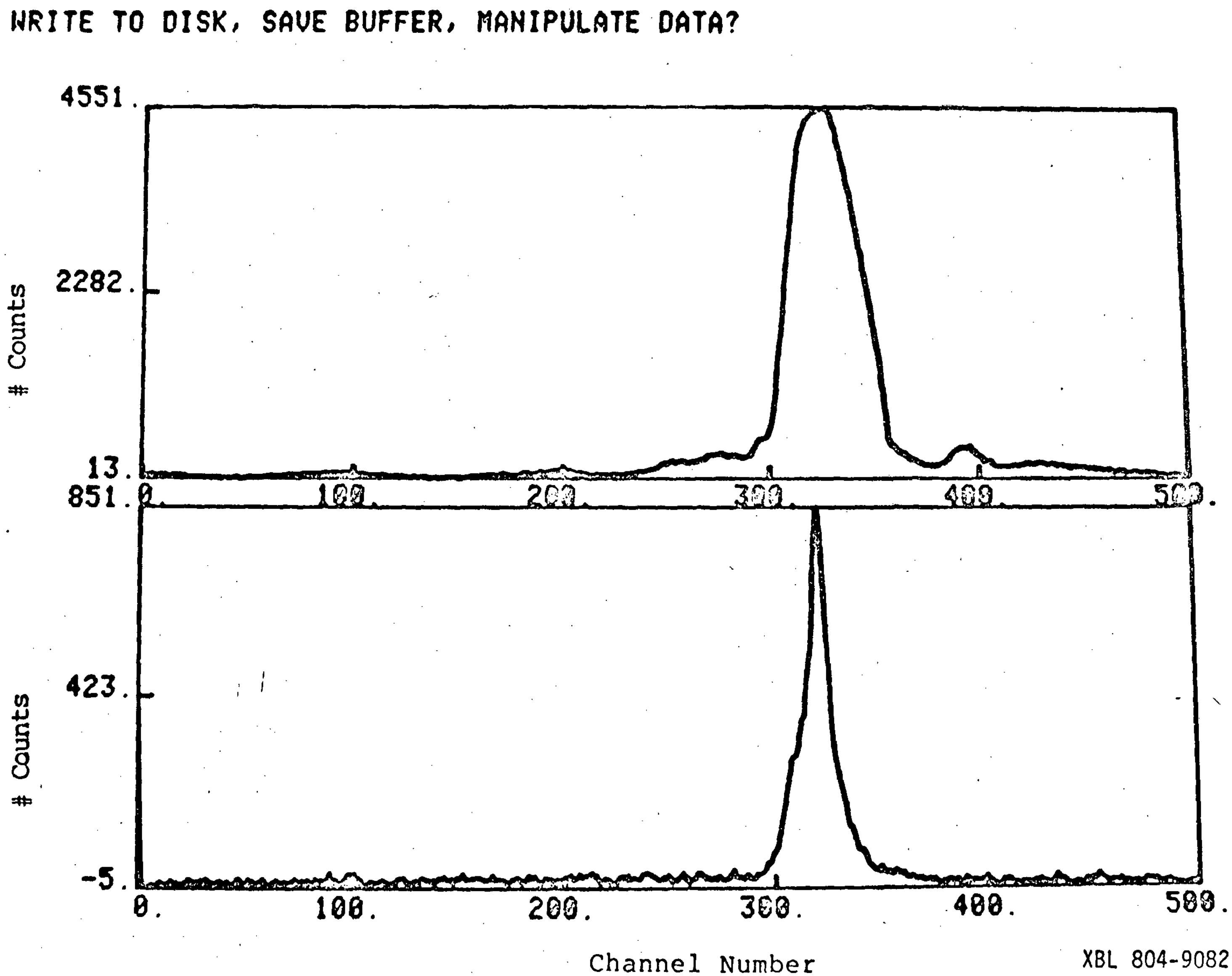


Figure 8 : Orthogonal polarizations are used to measure lineshapes from an excite and probe Stokes Stimulated Raman experiment.

Two-Track Picosecond Laser Generated Raman Spectra



XBL 804-9082

Figure 9 : Upper spectrum shows the probe Stokes emmission while lower one shows the excitation Stokes emmission.

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