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ENTITLED Photoreflectance Technique of Semiconductor Surfaces

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Instructor in Charge

APPROVED: Richard Alkire

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Photoreflectance Technique
of
Semiconductor Surfaces

By

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Thesis

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Abstract

Photoreflectance is a relatively new method for obtaining high resolution reflectivity measurements of semiconductor surfaces. This technique depends on reflection changes of a primary light source by an intense periodic secondary light source. There are advantages of employing photoreflectance over electroreflectance. Qualitative studies using photoreflectance were done while at the same time try to improve the method in the laboratory. Various parameters were changed, such as sample type and temperature. The experiments and results are found within.

Introduction

Photoreflectance is the spectroscopic method used to observe the electronic band structure on semiconductor surfaces. This method measures the reflection of a primary light source off of a semiconductor surface. The reflection intensity is perturbed by an intense modulated secondary light source, a He-Ne laser. The laser beam is chopped and has an energy greater than the fundamental bandgap energy. The laser beam pumps electron from filled to unfilled bands. This pumping can change the surface electric fields and can lead to Franz-Keldysh reflection effects.

Of all other spectroscopic methods used to study semiconductors, photoreflectance most resembles electroreflectance. In the electroreflectance technique, reflectance variations are due to an external electric field imposed on the surface in the space charge region. Electron hole pairs are created in the space charge region and are separated by the electric field. The electric field is added by contacting the surface with electrodes or an electrolytic solution. In photoreflectance, the potential change in the space charge region is made by a relatively intense laser beam which is made periodic in time by an optical chopper.

As opposed to electroreflectance, photoreflectance is a contactless technique for observing Eo and E1 transitions of electrons from the valence band to the conduction band. Contactless means that the source which changes the space charge on the surface of the sample does not physically touch the sample itself. For example, in electroreflectance the sample is placed in an electrolytic solution or the electrodes are attached to the sample. In which case, when the sample has semiinsulating properties, it is very difficult to run a current through the sample. On the other hand, photoreflectance uses a time modulated laser beam to perturb the reflectance of the primary light source. Also, electroreflectance spectra are strongly dependent on the magnitude of the applied field and on experimental conditions, so the determination of material parameters from these spectra is generally a difficult and uncertain process. Thus, photoreflectance opens up the possibilities of investigating different surfaces as well as surfaces adsorbed of various gases. The photoreflectance method is important since there is a considerable interest in the semiconductor industry in studying gas-surface interactions.

This paper will discuss in much detail the design of the new photoreflectance apparatus recently built in the Dr. Seebauer's laboratory. Preliminary experimental photoreflectance data will also be included. The main focus of study is with a GaAs surface due to its popular properties which can be used commercially in the semiconductor world. The surface theories for GaAs are complex because Ga and As have different chemical relativities. Photoreflectance spectra were taken of GaAs samples under various conditions. Photoreflectance on other samples were attempted as well.

Apparatus

The apparatus is shown in Figure 1. If the sample is GaAs and one wishes to observe the Eo spectrum, the primary light source would be a tungsten halogen lamp. This lamp emits high intensity light in the Eo range between 790 to 910 nm. In order to observe the E1 spectra, a xenon lamp would be used, since it emits high intensity light in the E1 transition range between 275 and 500 nm..

The light is scanned by a monochromator (Photon Technology Inc.) whose driver is controlled by a computer. The slit width of the monochromator is set at a certain value. The size of the slit width is inversely proportional to the resolution and directly proportional to the signal to noise ratio. In other words, decreasing the slit width increases the resolution of the signal. Decreasing the slit width decreases the signal to noise ratio. So, therefore, the slit width must be chosen accordingly. The light is then focused onto the sample by a series of two lenses (See Figure 2). The first lens takes the diverging light from the monochomator and makes the light parallel. The second lens then takes the parallel light and focuses it onto the sample which is located at the focal length of the second lens.

The primary light source is perturbed by a high intensity, modulated secondary light source. This source is a twenty milliwatt helium neon (He-Ne) lamp by Spectra Physics, Inc. which emits light at 632.8 nm. The laser is made periodic in time by using an optical chopper. This light is to be focused on the sample as well. The sample is suspended inside a vacuum chamber by a sample holder. It is necessary that the primary and secondary light are incident at the exact spot on the sample, which means that the shape of the two light sources on the sample should be the same. The primary light is rectangular since the slit from the monochromator is rectangular. The laser light is initially a single beam with a one centimeter diameter. The beam is elongated in the vertical direction by a cylindrical lens. The beam is widened in the horizontal direction by a spherical lens. The now rectangular light is reflected onto the sample through a window using a mirror. The laser light is passed through a window different from the window of the primary light. Having this arrangement cuts down on the amount of stray laser light which contributes to much of the noise in the photoreflectance signal.

In the most recent experimental setup, the sample is located inside a vacuum chamber. The vacuum chamber is designed to achieve vacuum pressures of nanotorrs or better. These pressures are achieved by using a roughing pump, a cryopump and by baking out the system overnight. In order to do surface studies, it is preferable to have a sample under vacuum rather than exposing the sample to ambient air. Having the sample under vacuum conditions allows for better control over the surface of the sample. Thus, it makes it possible for experiments to be done under known conditions of the surface of the sample.

The reflection of the primary light goes into another series of two lenses. These lenses have the same function as the first series of lenses mentioned. However, located at the focal length of the second lens, there is a Si photodiode which generates the photons of the light into current. The number of photons hitting the surface of the photodiode is directly proportional to the amount of current produced. To eliminate stray light, which may come from the laser or other extraneous sources other than the primary light, filters were added before the light reaches the photodiode. For an Eo spectrum two long pass, Schott glass type filters are used with a fifty percent cut off wavelength at 780 nm. For the E1 spectra, one bandpass filter is used.

The current from the photodiode is then amplified by an amplifier. The typical amplification factor is 10^7. The current is composed of both alternating and direct. The direct current represents the reflectivity (R) of the light due to the primary light. The He-Ne laser (modulated secondary light source) varies the electric field in the space charge region of the semiconductor surface which changes the reflectivity (dR). This change is seen as the alternating current which goes into a Stanford Research System lock-in amplifier. In the lock-in amplifier the ac current is referenced against the reference frequency taken from the optical chopper. The output reflectance signal is directly proportional to dR/R, the relative change in reflectance. This signal is preferred because this number automatically corrects for any fluctuations in the reflected intensity due to changes in the incident light intensity or variations on the surface of the sample.

Using a divider the output signal from the lock-in amplifier is divided by the R signal from the amplifier. The result is dR/R. A data acquisition program was written to keep track of this signal as well as control the driver of the monochromator. A copy of the program is included in the Appendix. A macro was written in Lotus to plot dR/R versus energy (eV) and hardcopies can be made using a Hewlett Packard plotter. For an overview, Figure 3 shows a very rough schematic of the key pieces of equipment and the signal for photoreflectance.

Procedure

The first step is to set up the apparatus after baking out the system. Then, it is necessary to align the optics, in order to maximize the number of photons focused on the photodiode. It is also important that the laser light is exactly incident to the primary light source. At this point a slit width and an amplification factor on the amplifier is chosen.

The next step is to find the peak by turning the driver of the monochromator to maximum deflection on the X output reading on the lock-in amplifier. At the same time, adjust the sensitivity to a scale where the peak will not overload circuits. When the display is set at theta phase, the REL key sets the reference phase ft to the absolute phase difference between the signal and the reference. After the auto-phase is performed, the theta output will be zeroed, and R will be unchanged. Also, X will be maximized and Y will be minimized.

At this point, place the driver of the monochromator to the beginning wavelength of the photoreflectance scan. This wavelength should be greater than the end wavelength. Access the computer program in the basic file called 5a.bas and input the necessary information outlined in the program. The computer will drive the monochromator and keep track of the signal from the divider. At the end of the scan, the plot of dR/R versus Energy (eV) can be made by using a macro file entitled BBB.

Experimental

Several different experiments were done and will be described. At first, there was a very rough apparatus setup which contained all the major equipment pieces. However, the sample was not inside a vacuum chamber. Instead, it was exposed to ambient air and the data aquisition program was not written so the signal from the divider was taken by a Sargent-Welch chart recorder. A photoreflectance spectra of the Eo transition of GaAs was taken. The data is shown in Figure 4. With the rough apparatus, silicon was used as the sample, but no photoreflectance results could be found for either Eo or E1.

New designs for the vacuum system, sample holder, and computer-aided programs were developed and installed. All the optics and remaining equipment were then setup. The most difficult part of the apparatus was to get rid of all the stray light which contributed to much of the noise in the photoreflectance signal. To reduce the noise, filters were added just before the photodiode which eliminates light at 632.8 nm, which is the wavelength of the He-Ne laser. There is still noise in the system, but it is now reduced to a more acceptable level.

With the sample under vacuum conditions several experimental runs were done with various parameters changed in each one. Figures 5 through 14 show photoreflectance spectra of GaAs at different temperatures. The sample was first cooled to approximately -100 C. This was done by pouring liquid nitrogen in a stainless steel port on top of the vacuum chamber which is attached to the arm of the sample holder. By its design, the sample is cooled by conduction and radiation. Due to poor design of the metal contacts leading to the sample, the coolest temperature that could be achieved was 173 K where liquid nitrogen temperature is 77 K.

In comparing the data of the surface of GaAs taken under different temperatures (Figures 5 - 14), one could see that as the temperature of the surface rises the features of the photoreflectance peak disappears. Going to cooler temperatures, the peak intensity becomes greater. Also, at cooler temperatures peaks tend to shift to greater energies and the width of the peaks become smaller. The spacing of adjacent peaks as the temperature is decreased from 146 C to -95 C becomes smaller. This may indicate that the surface electric field is decreasing. This means that the band bending decreases as the temperature is decreased.

Figures 5 through 15 show photoreflectance spectra of GaAs with the monochromator slit width at 0.027 cm. Figure 16 shows the sample of GaAs at room temperature with a slit width of 0.015 cm. In comparing Figure 16 to Figure 9 (GaAs at room temperature), one notices that the spectra taken at a smaller slit width (Figure 16) had a worse signal to noise ratio than Figure 9. Figure 9 also has better resolution. Both of these observations agree with the theory that the size of the slit width is inversely proportional to the resolution and directly proportional to the signal to noise ratio.

A new instrument which is designed to clean the surface of a mounted sample was tested. The device is called a sputtering gun and its purpose is to shoot Ar gas to the surface of the sample and diffuse the dirt that may be on the sample. The sputtering gun was tested and a photoreflectance spectra was taken of the surface afterwards. The photoreflectance result is shown in Figure 17. This data is quite different from previous spectra taken of the same sample. It was found upon inspection of the surface after trying to acid etch the sample that the sputtering gun damaged the surface leaving two white circles on the surface. I suspect that this was the cause of the distorted photoreflectance spectra.

Finally, another sample was mounted in the sample holder. This time the sample was indium antinimide (InSb) received from the Navy. No photoreflectance peak could be found for either the E1 or Eo transitions. A possible reason for this was because the surface potential of the clean surface was too small. But if a gas, such as CO2 or H2, was to be adsorbed onto the surface, the surface potential would increase and perhaps a photoreflectance spectra may be observed. This may also be the reason why a photoreflectance spectrum could not be found for Si.

Conclusion

A complete picture of the design of the new photoreflectance apparatus with descriptions of the various pieces of equipment were just described. The temperature dependence of the GaAs photoreflectance line shapes show that the photoreflectance peaks become broader and peak spacing become longer as temperature increases. The photoreflectance on surfaces of Si and InSb were not found. Perhaps due to a small surface potential which could be increased by adsorbing a gas on the surface.

To make the study of the semiconductor surfaces more complete the photoreflectance results will be pulled together with results from other experimental techniques done in Dr. Seebauer's group. These techniques include Auger electron spectroscopy, Low Electron Energy Diffraction (LEED), Second Harmonic Generation (SHG), and Temperature Programmed Desorption (TPD).

Acknowledgements

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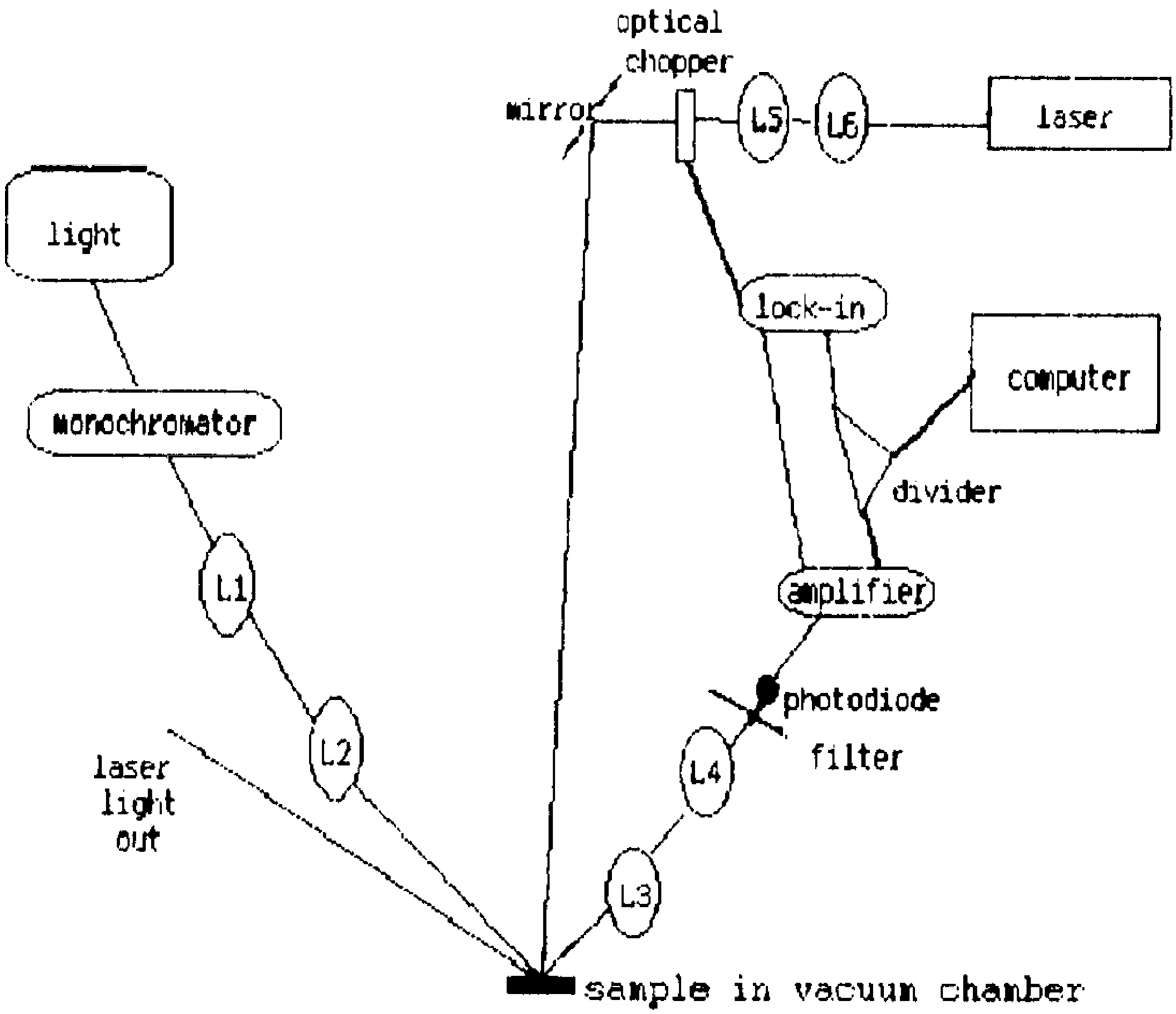


Figure 1 - Photoreflectance Apparatus

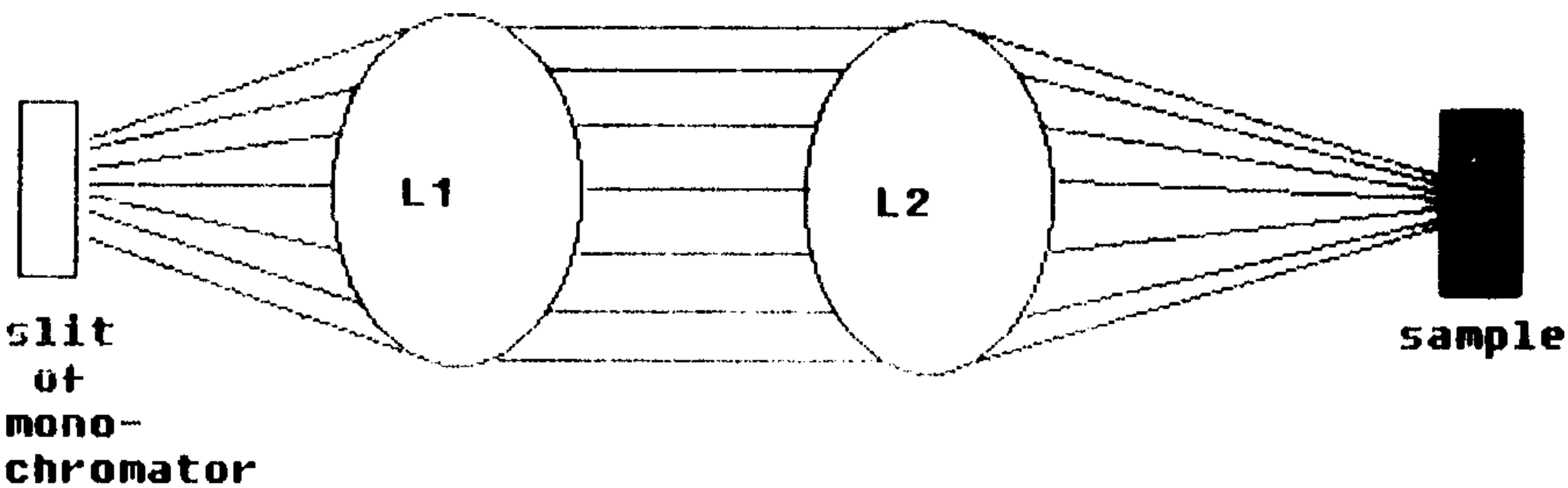


Figure 2 - Lens Arrangement

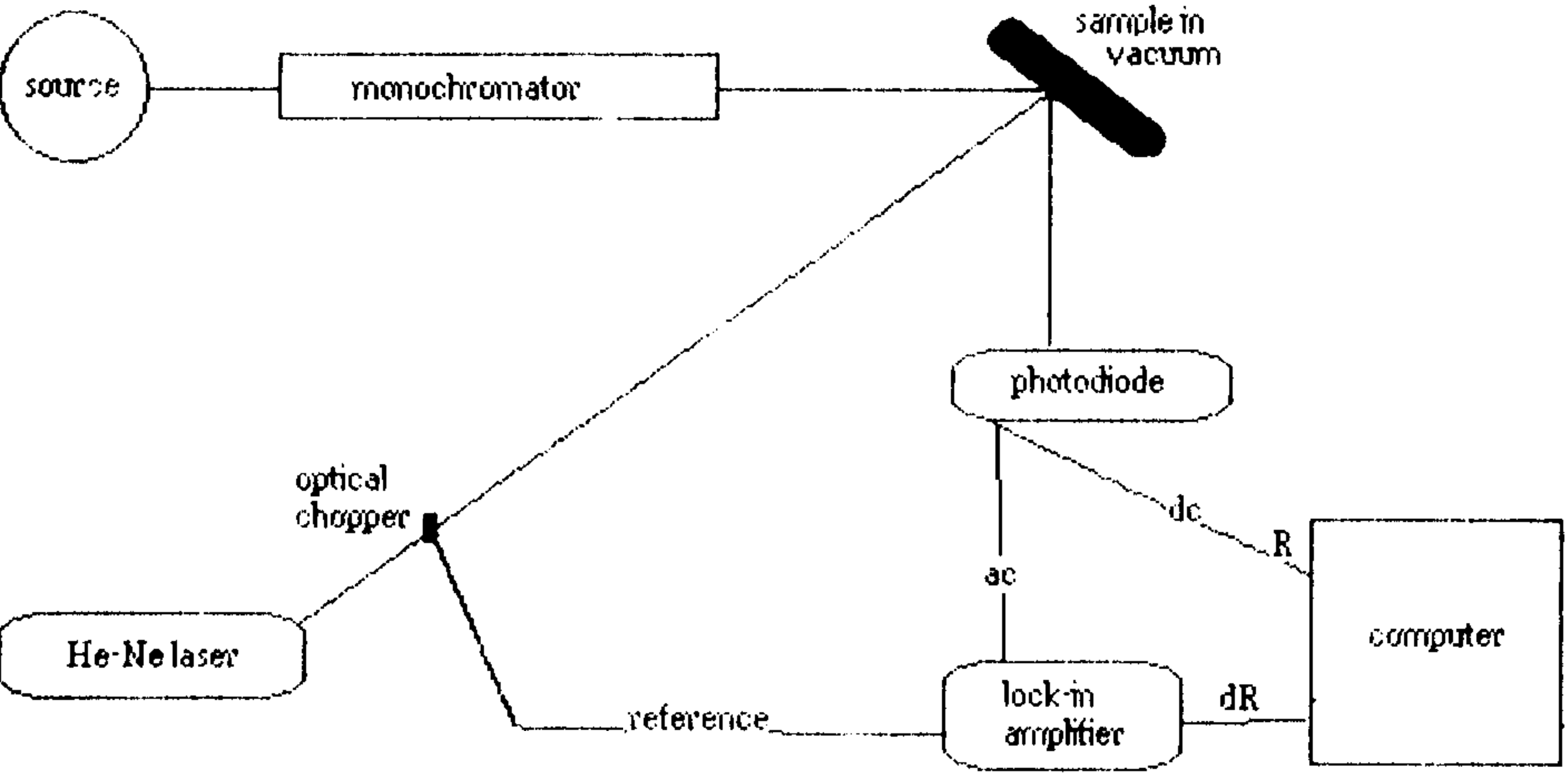


Figure 3 - Rough Apparatus Schematic

Figure 4 - GaAs in ambient air, E_o

data file A19	f(HZ) = 932	Temp 2.455 – 2.456 mV −95 °C
Sample GaAs	LIA sensitivity 100 μV	scanning speed 5 Å/s
(E_0) on E_1	time constant 30 ms	ref: 77K
slit (mm) = 0.2 mm	S 35.7	

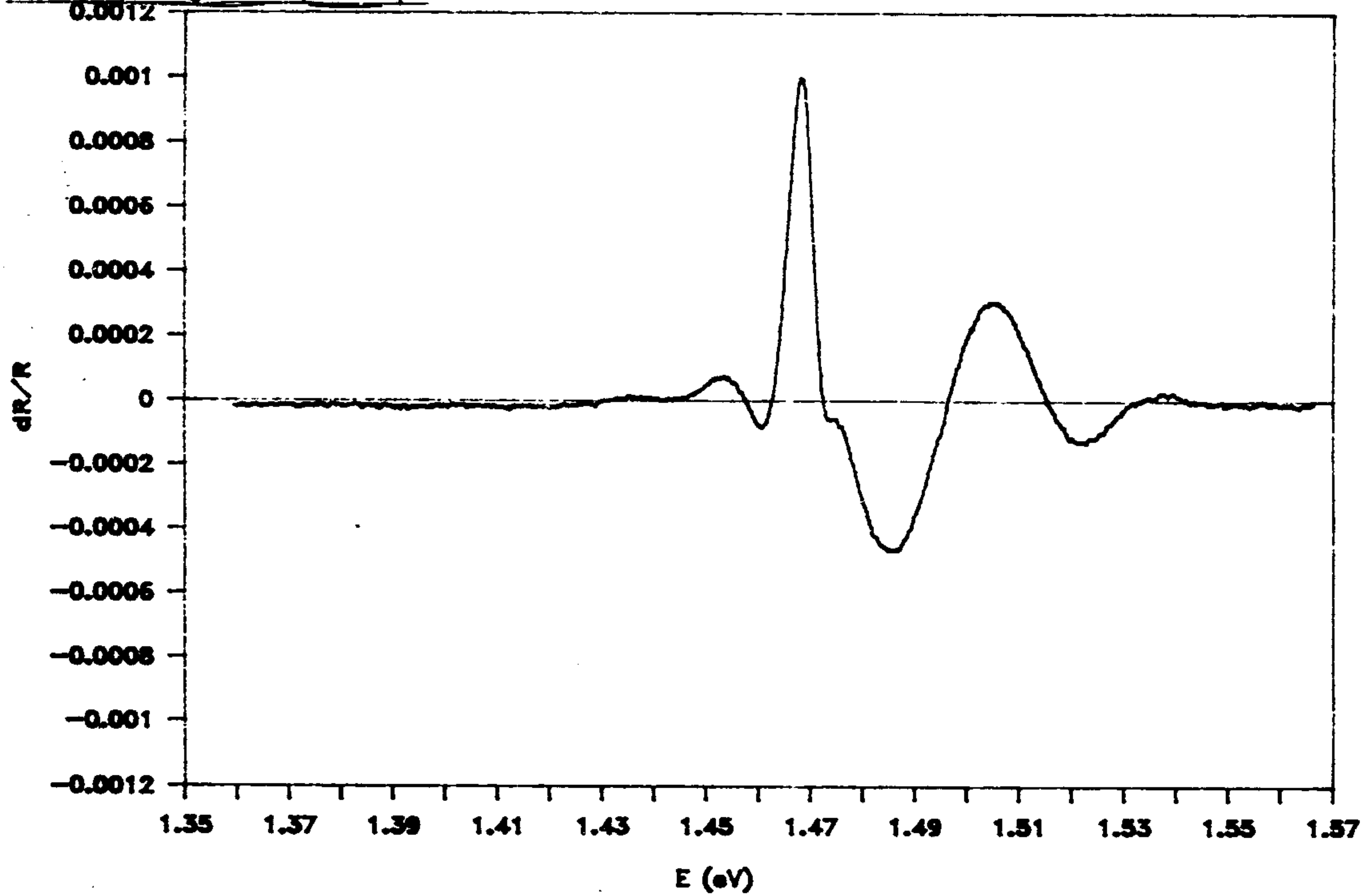


Figure 5, E_0 transition T = −95°C

data file A17	f(HZ) = 932	Temp 3.01~3.02 mV
Sample GaAs	LIA sensitivity 150 μV	scanning speed 5 Å/sec
E_0 on E_1	time constant 300 ms	ref: 77K
slit (mm) = 0.29 mm	δ 34.2	

−77 °C

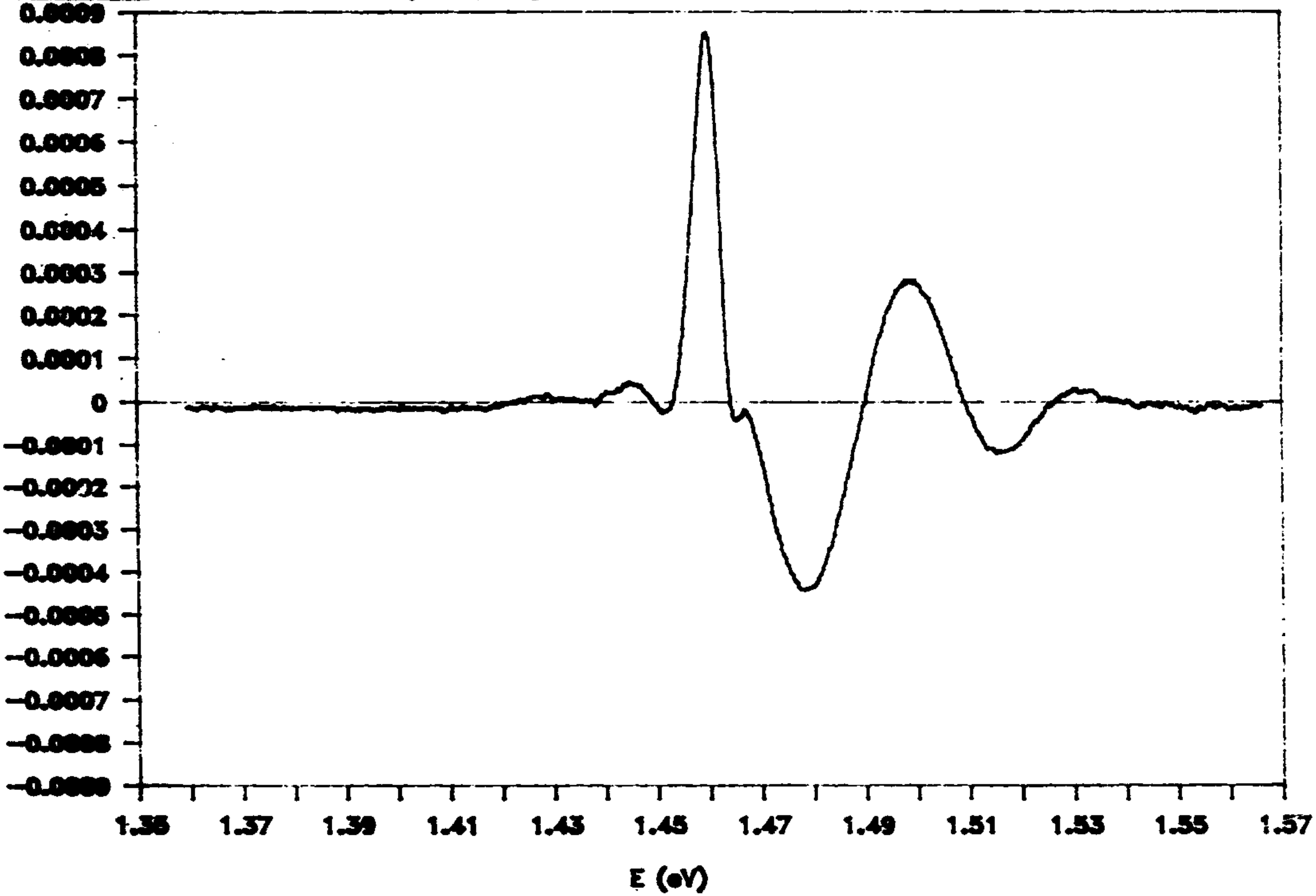


Figure 6 - E_0 transition T= -77°C

-34°C

data file A14	f(HZ) = 932	Temp 4.55mv ~ 4.56mv
Sample GaAs	LIA sensitivity 100µ	scanning speed 5Å/sec
E_0 or E_1	time constant 300 ms	910nm, 0.133 x10^-6
slit (mm) = 0.29mm	δ 35.2°	ref = 77K

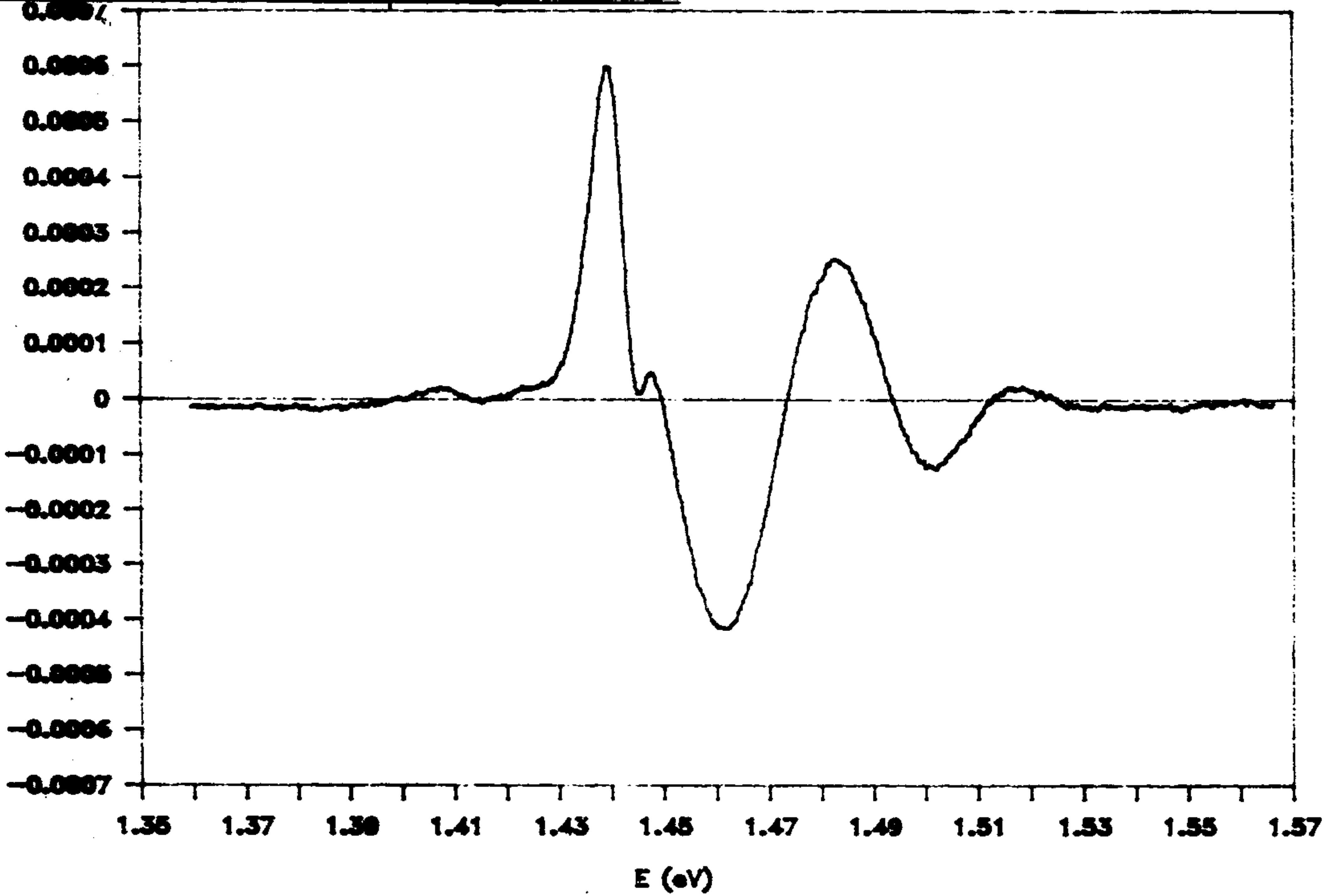
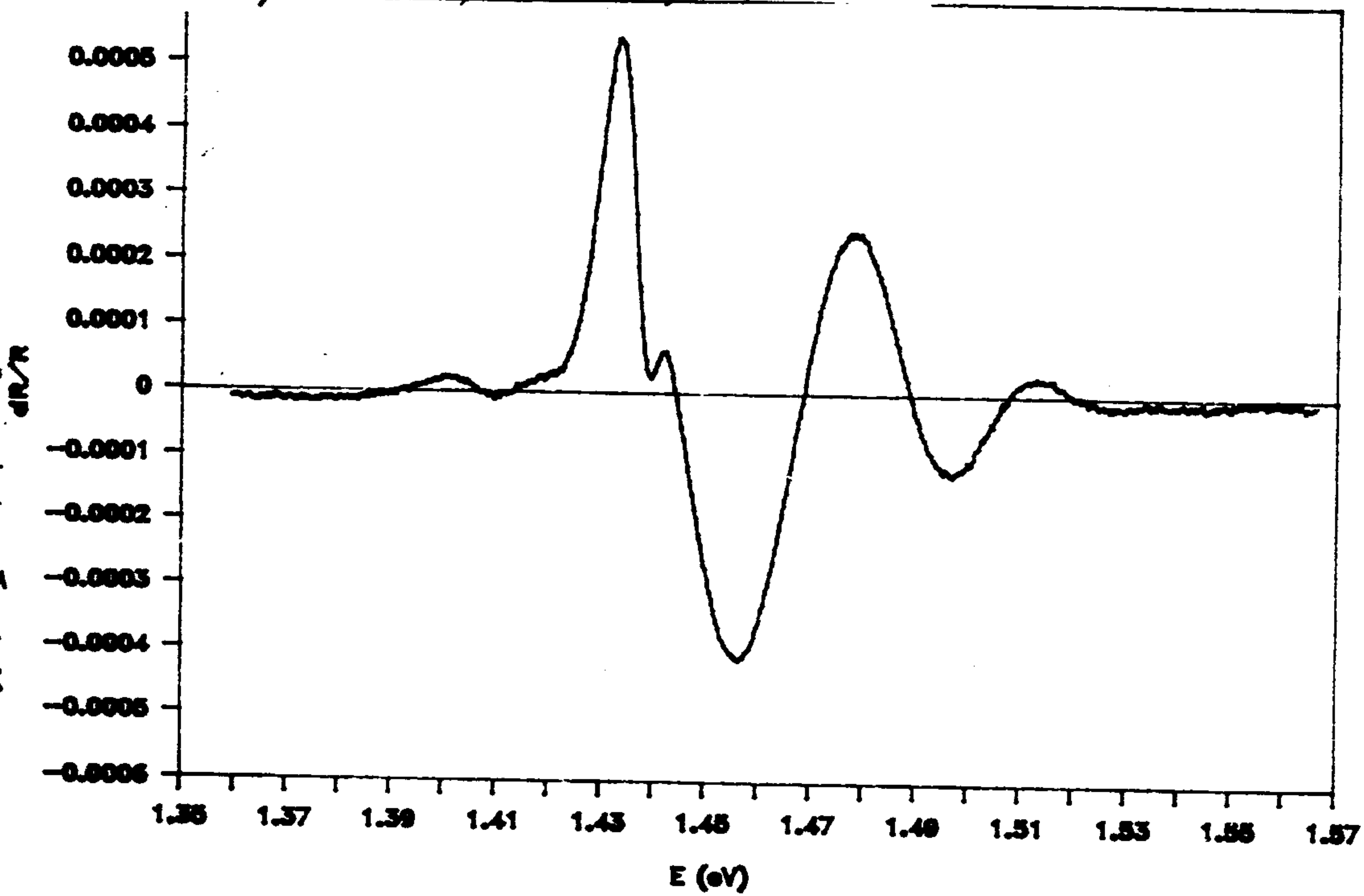


Figure 7 - E_0 transition T = -34°C

-22°C

data file A13	f(Hz)= 932	Temp 4.99~5.00 mV
Sample GaAs	LIA sensitivity 100	scanning speed 5Å/sec
E_0 on E_1	time constant 300 ms	910nm. 0.133×10^{-6} m..
slit (mm)= 0.2	δ 44.3	ref: 77K



data file A12	f(Hz)= 932	Temp 5.81~5.82 mV	0°C
Sample GaAs	LIA sensitivity 10 μV	scanning speed 5 Å/sec	
E_0 or E_1	time constant 3s	910 nm 0.133×10^{-6} V	
slit (mm)=0.29 mm	δ 44.2	ref: 77K	

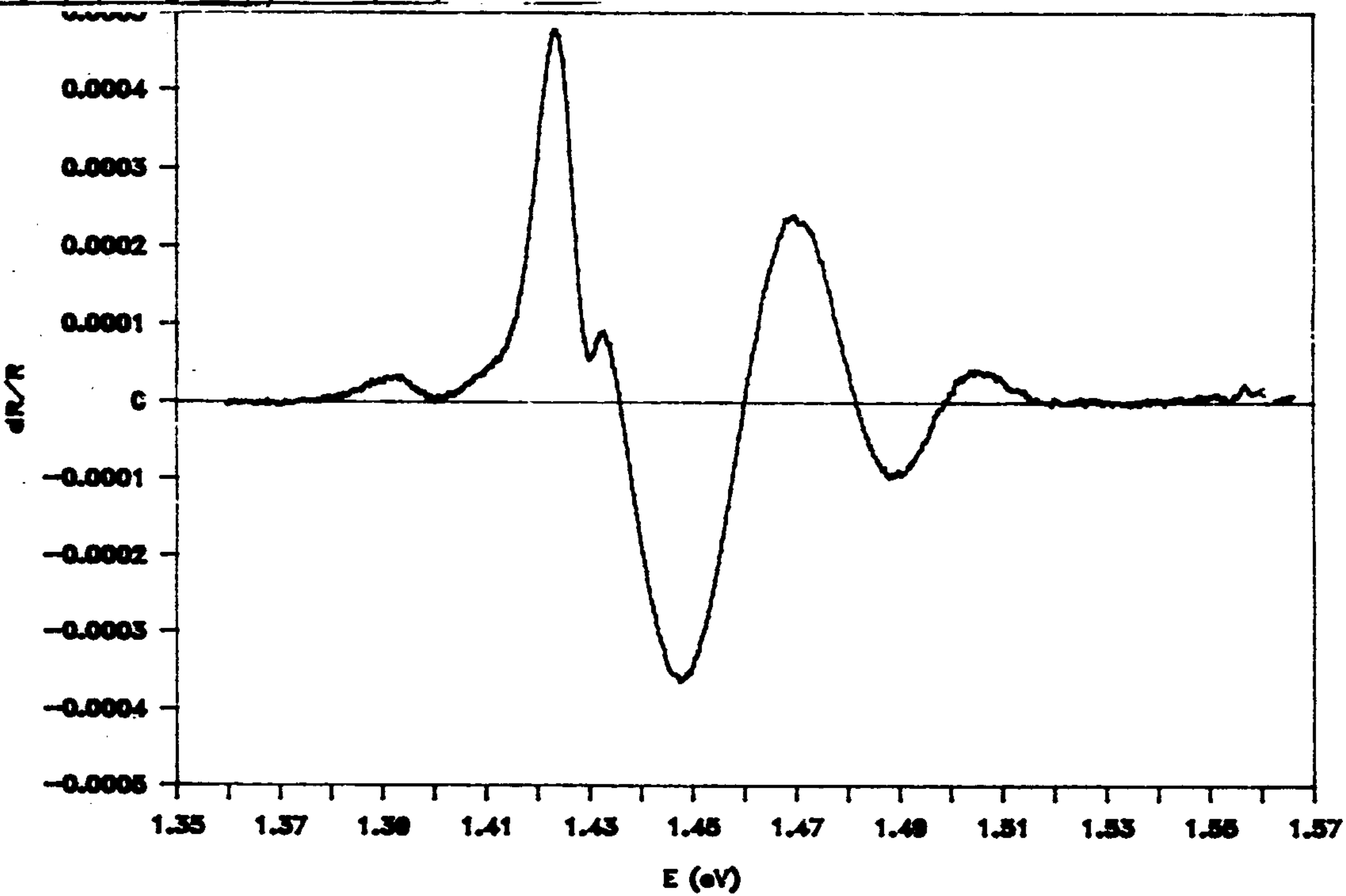


Figure 9 - E_0 transition T= 0°C

Data file A11	f(HZ)= 932	Temp -0.026ev	24°C
Sample GaAs	LIA sensitivity 5µV	scanning speed	
E_0 or E_1	time constant 3s	910mm φ=31.54	
slit (mm)=	δ 35.7	0.133×10^{-6} v ref: room 7	

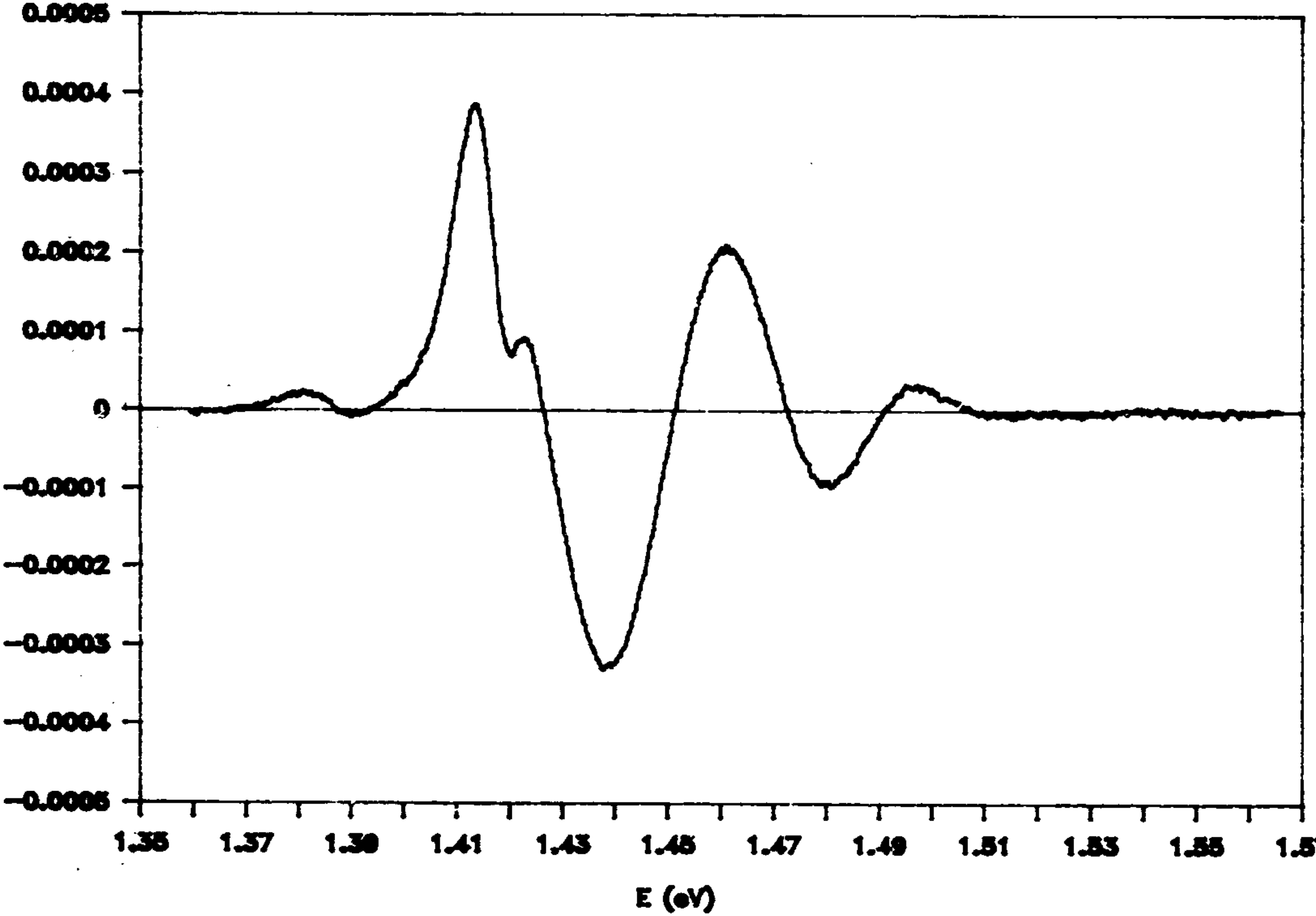


Figure 10 - E_0 transition T = 24°C slit width = 0.02 mm

data file A7	f(Hz) = 93C	Temp 1.360 ~ 1.370 mV 59°C
Sample GaAs	LIA sensitivity 50 μV	Scanning speed 5 Å/sec
Eg or E_1	time constant 300 ms	glom 0.18×10^{-6} V
slit (mm) = 0.2 μ	δ 33.2°	ref: room Temp

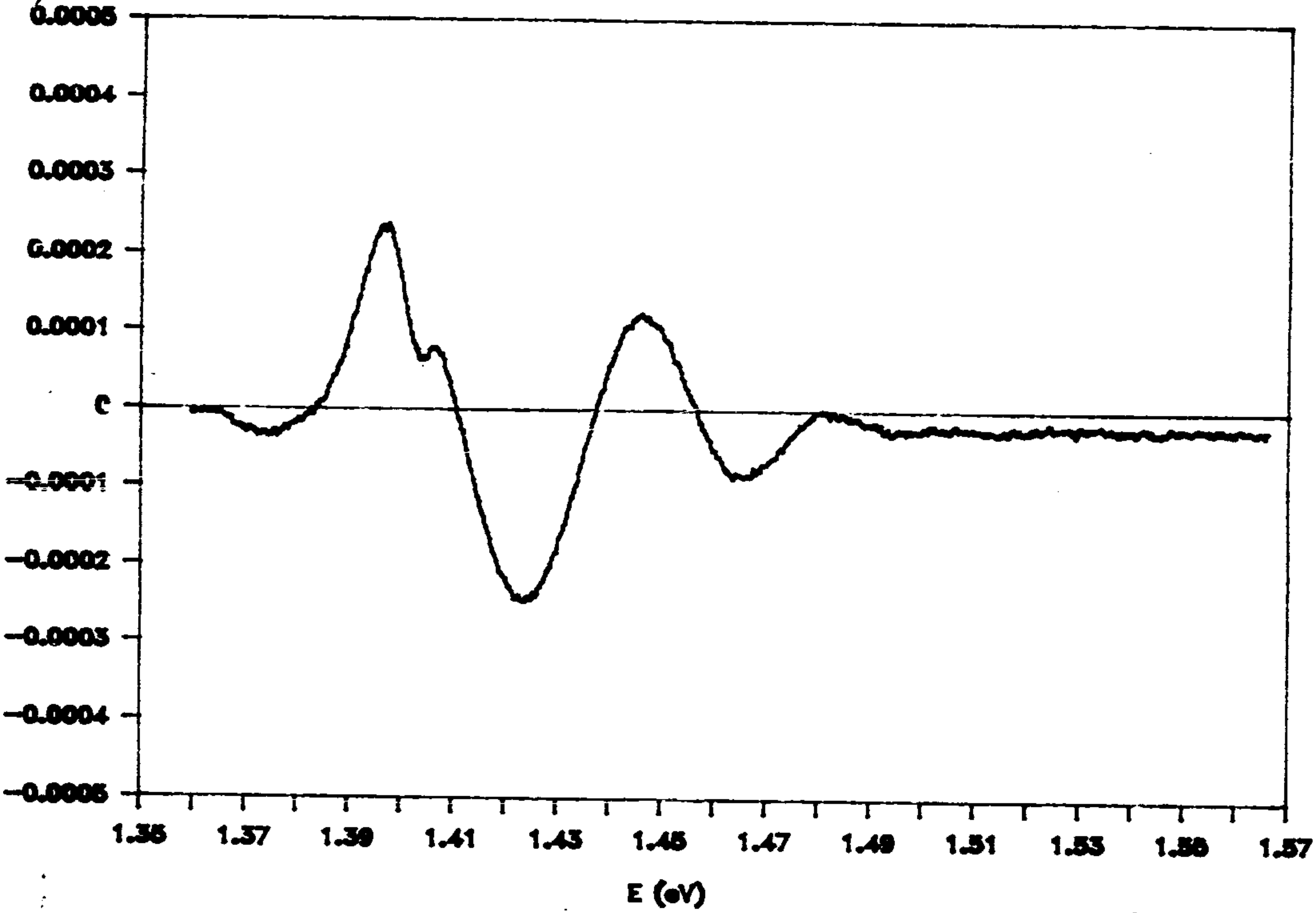


Figure 11 - E_0 transition T = 59°C

data file A8	f(Hz) = 932	Temp 2.49~2.47 mV 85°C
Sample GaAs	LIA sensitivity 20 μV	scanning speed 5 Å/sec
E_0 or E_1	time constant 300 ms	Ref = room Temp
slit (mm) = 0.27 mm	δ 41.1°	0.093 V at 910 nm

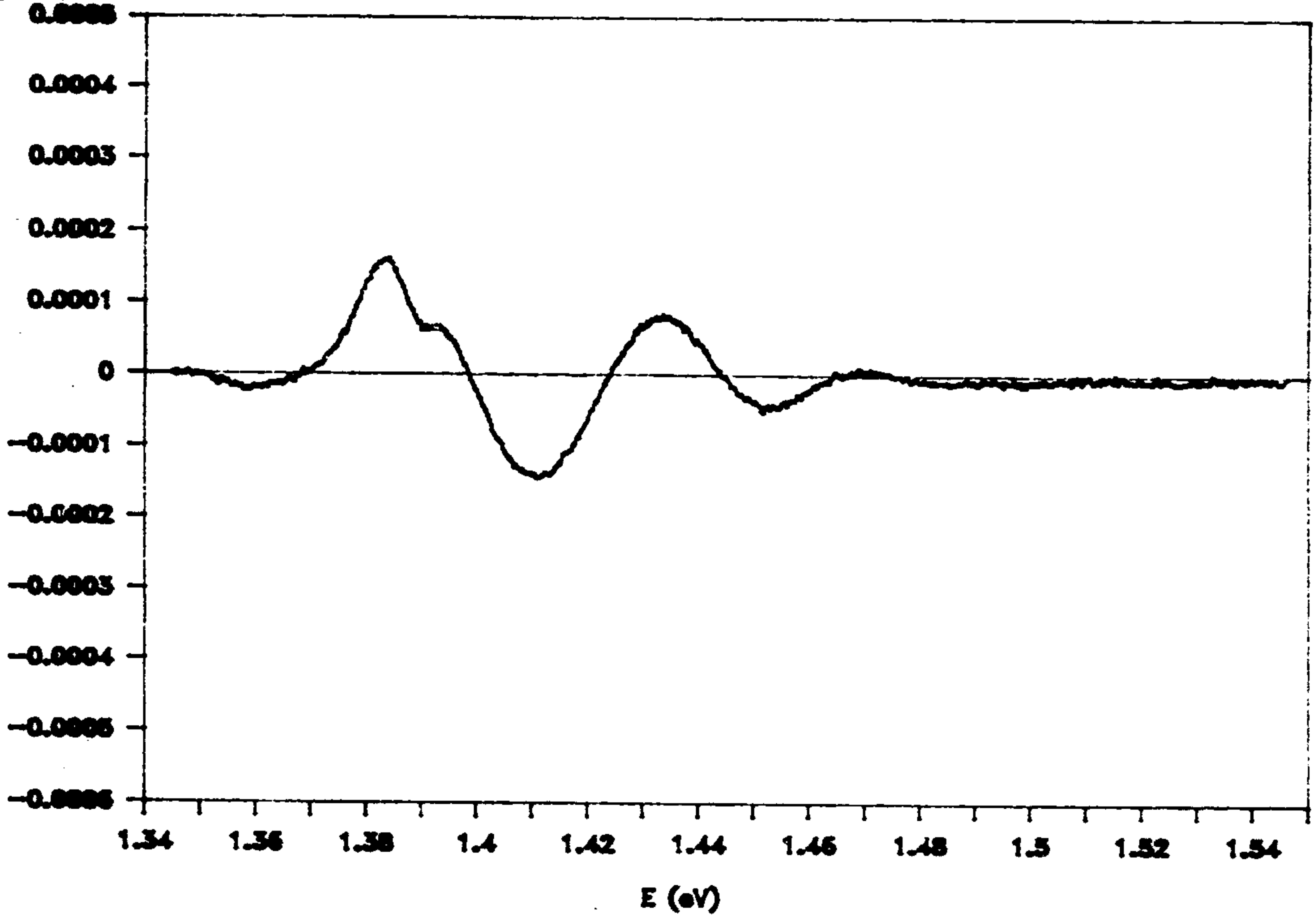


Figure 12 - E_0 transition T = 85°C

data file A9	f(Hz) = 932	Temp 3.75 ~ 3.78 mV 110 °C
Sample GaAs	LIA sensitivity 10 μV	Scanning speed 5 Å
(E_0) or E_1	time constant 300 ms	gain 0.95 × 10^6 V
slit (min) = 0.79 mm	δ 35.5°	ref: room Temp

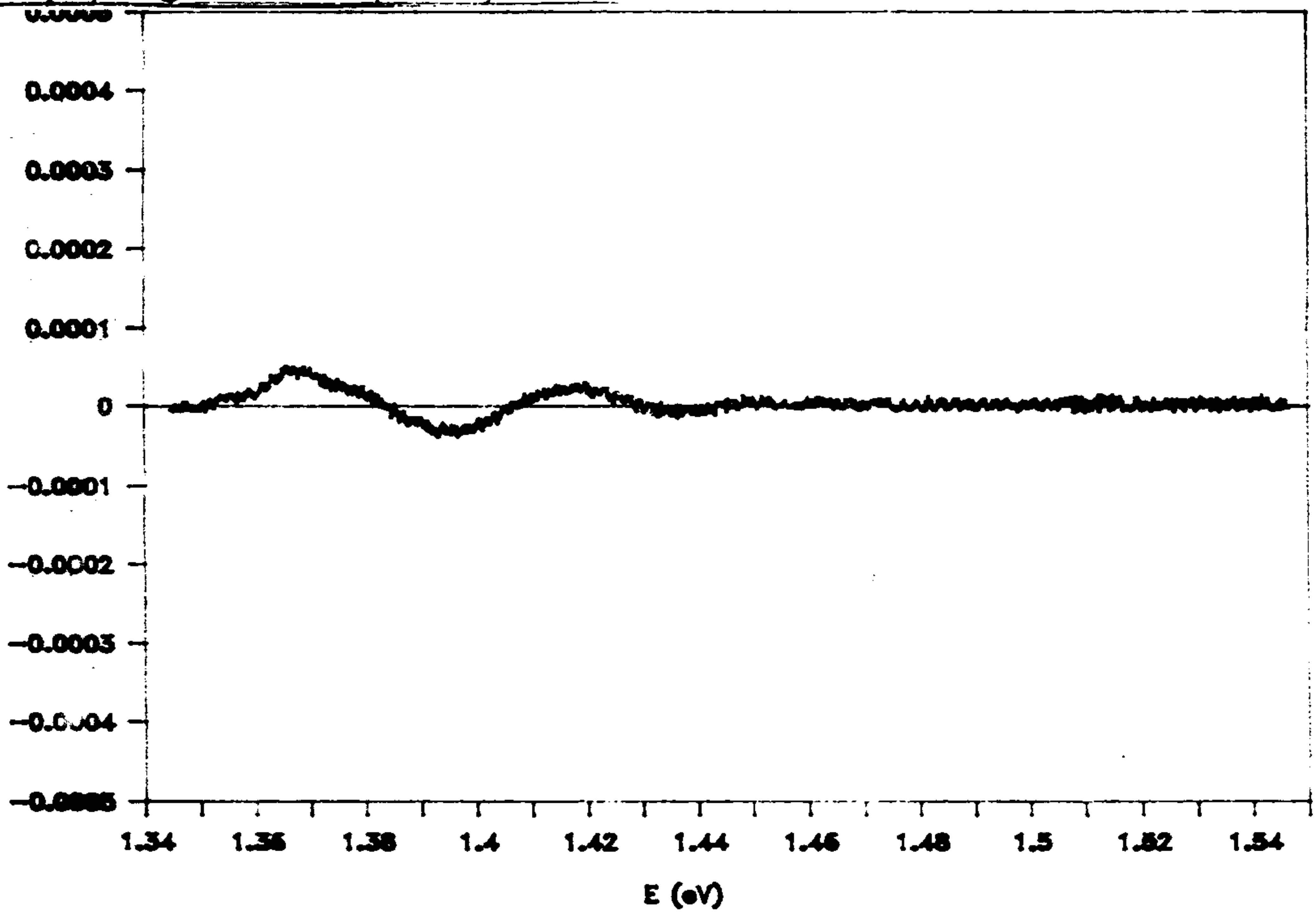


Figure 15 - E_0 transition T = 110 °C

ata file A10	f(HZ) = 932	Temp [illegible] 146 °C
ample GaAs	LIA sensitivity 10 μV	scanning speed 5 Å/s
[illegible] on E_1	time constant	gi: [illegible] × 10^6
lit (mm) = [illegible]	[illegible] -0.4	ref: room Temp

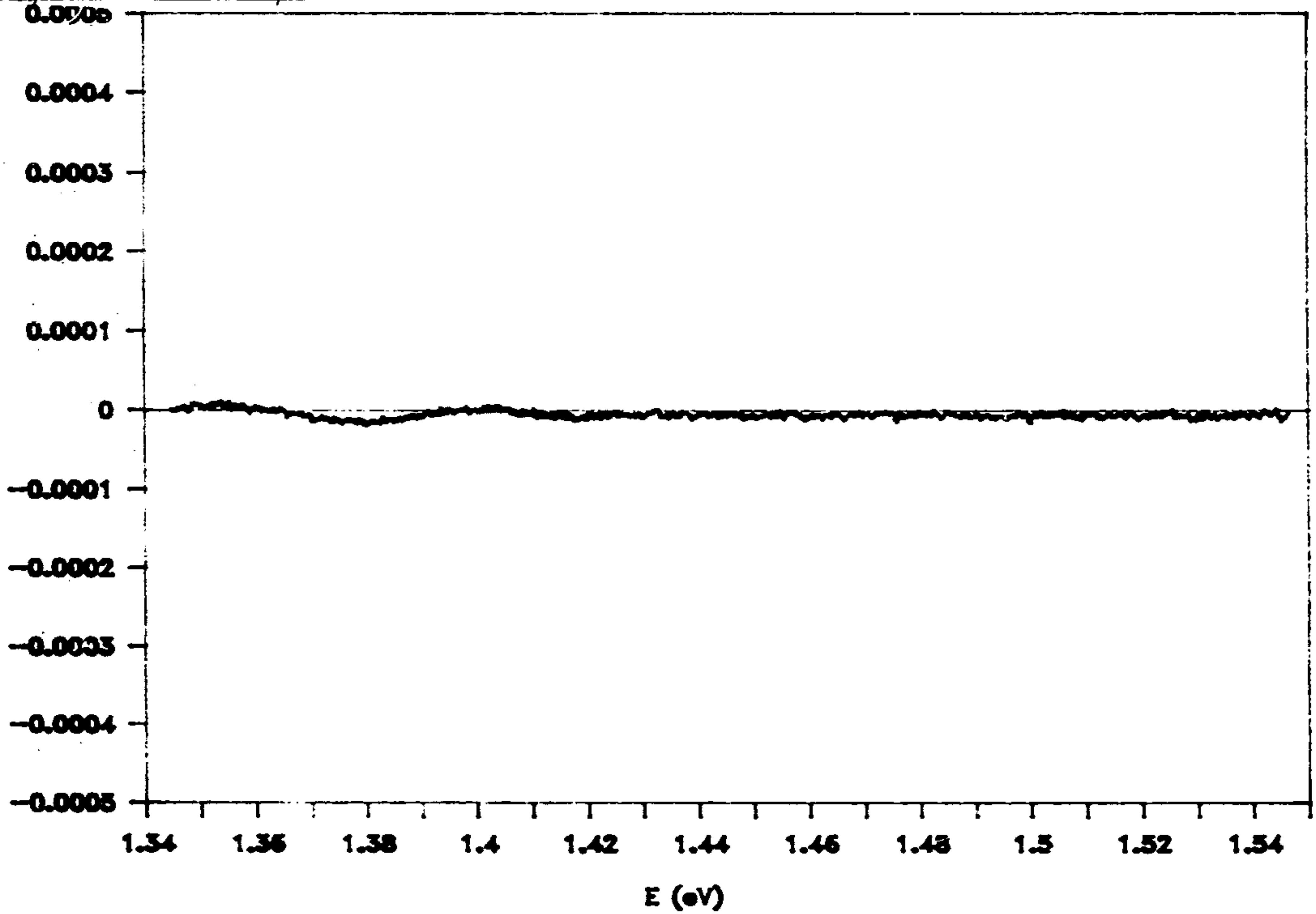
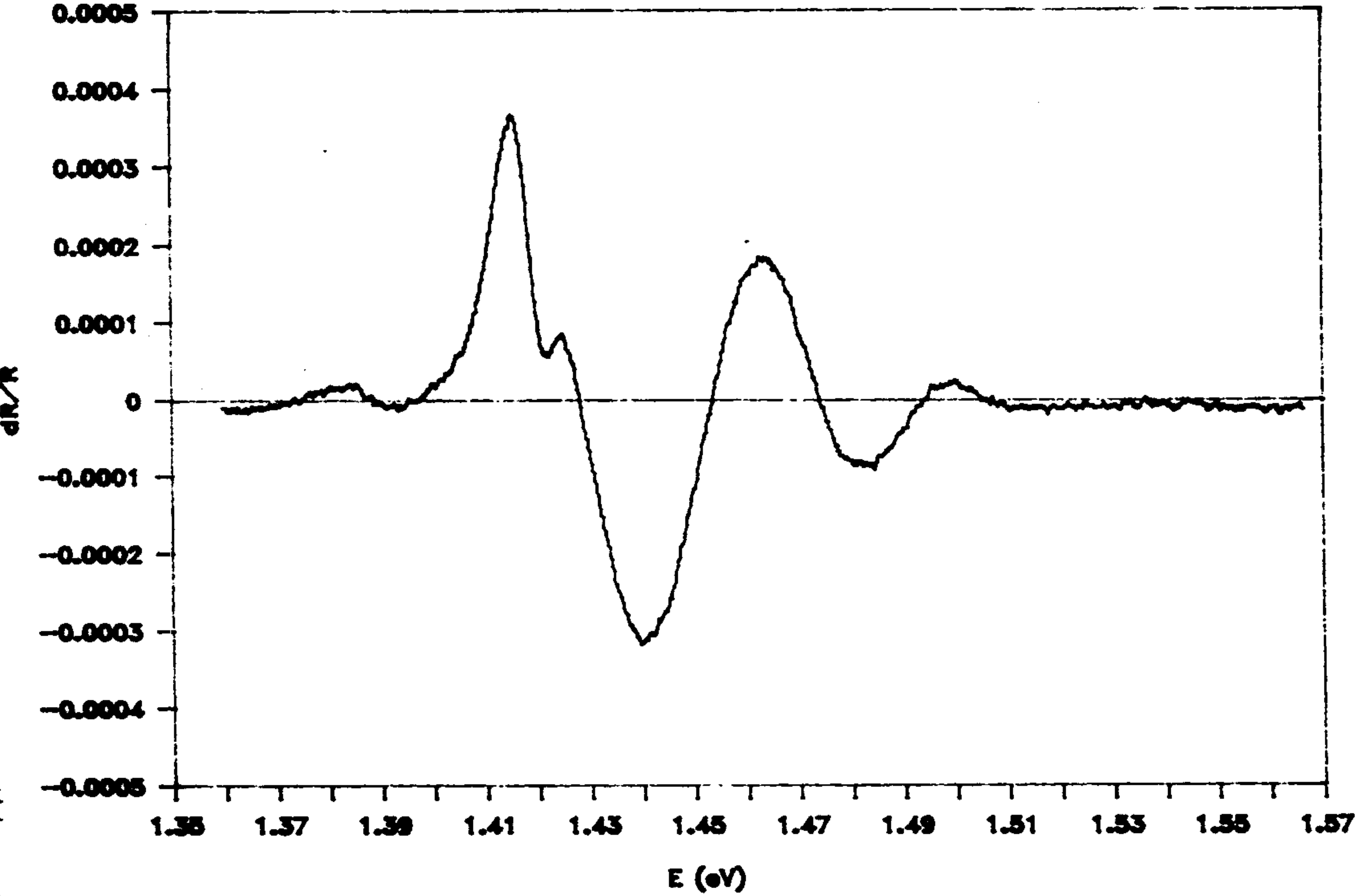


Figure 14 - E_0 transition T = 146 °C

z data file A22	f(Hz)= 932	Temp -0.0f m	24°C
Sample GaAs	LIA sensitivity 20 μV	scanning speed 5 ...	
(Eg) on E1	time constant 1sec		
slit (mm)= 0.15 m	δ 23.1		

Ø slit smaller



slit width :0.015 cm

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data file A63	f(Hz) = 929	Temp ≈ 0.33 ~ 2 mV
Sample GaAs	LIA sensitivity 50 μ	scanning speed 5 Å/s
E_0 on E_1	time constant 1	
slit (mm) = 0.27	δ 41.6 [illegible]	

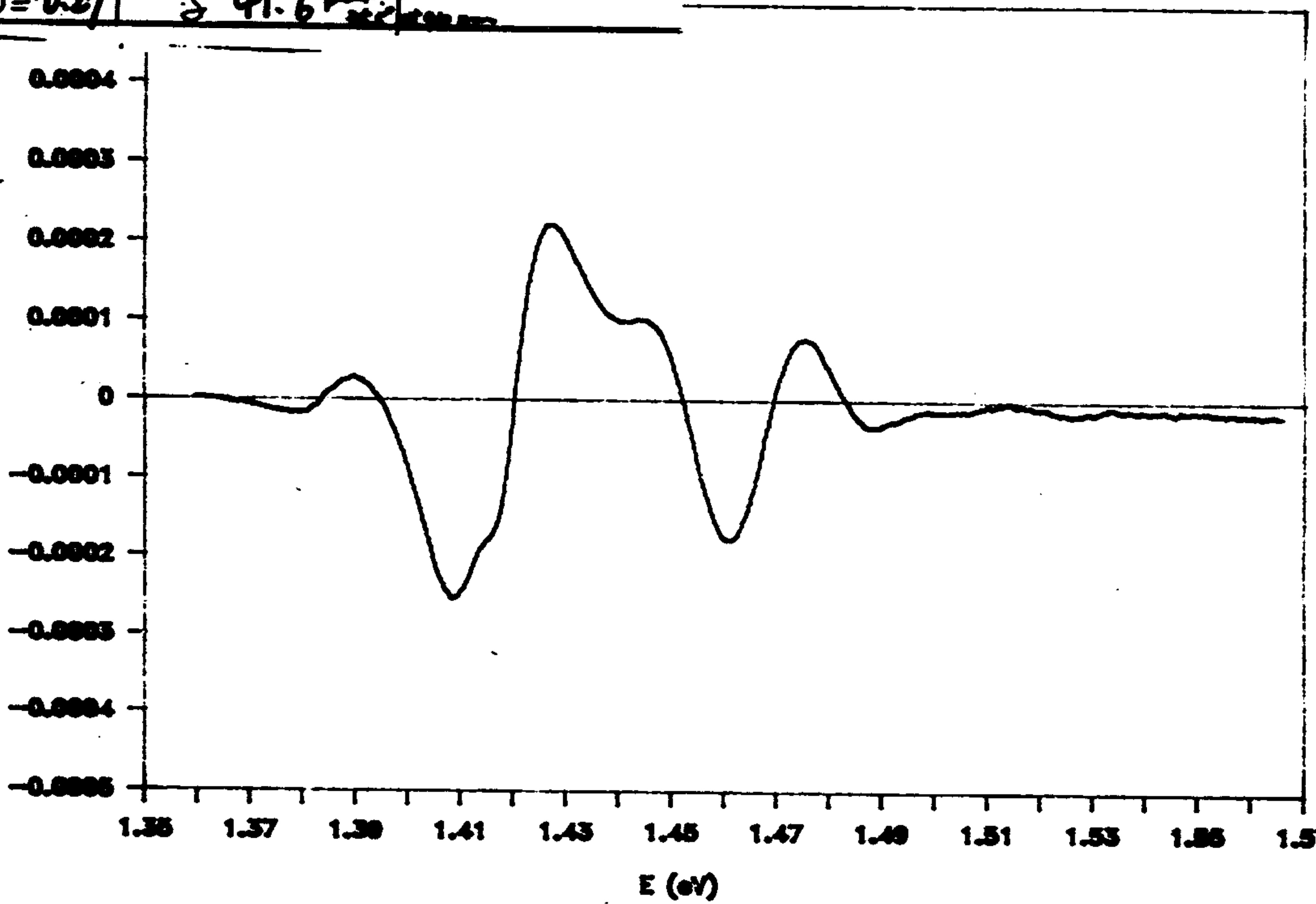

Figure 16 - E_0 transition, T = 24°C damaged GaAs surface

```
10 ' THE PROGRAM IS REVISED BY PROFESSOR SEEBAUER'S GROUP
20 INPUT "***** Output File Name (a:file.prn) ";FILE$
30 CLS
40 INPUT "input the sensitivity of lock-in (V)";SENSI
50 CLS
60 INPUT  "input the amplification factor of the 2nd amplifier";AMP
70 CLS
80 PRINT "****INPUT SAMPLING TIME (SEC) & SAMPLING FREQ.(#/SEC)"
90 PRINT "SPEED = 5A/SEC, SAMPLING TIME=RANGE OF SCANNING WAVELENGTH(A)/5"
100 INPUT TIME1,SAMT
110 CLS
120 IMAX=TIME1*SAMT
130 SAMTM1=1/SAMT
140 DIM T (3000), AVGDATA! (3000)
150 DIM VOLT(3000),WAVE(3000),ENG(3000)
160 '
170 '
180 '
190 '  Define segment that the 5011 is located in.
200 '
210 DEF SEG = &HD000
220 '
230 '  Make sure the motor is not moving
240 '
250 POKE 1020,ASC("S")
260 POKE 1021,ASC("T")
270 POKE 1023,ASC("A")
280 '
290 '  Set position of motor A in nm
300 PRINT "Input the position of monochromator, 100--1080 nm"
310 INPUT POSI
320 CLS
330 IF POSI > 600 THEN CALI=1  'BLAZE-700nm WAVELENGTH CALIBRATION'
340                ELSE CALI=2  'BLAZE-450nm WAVELENGTH CALIBRATION'
350 IF POSI <100 OR POSI >1080 GOTO 2460
360 POSI=POSI*4    'change nm to steps; 100 nm =400 steps'
370 IF POSI<256 THEN GOTO 460
380 A$=HEX$(POSI)
390 B$=LEFT$(A$,1)
400 C$=RIGHT$(A$,2)
410 B$="&H"+B$
420 C$="&H"+C$
430 B=VAL(B$)
440 C=VAL(C$)
450 GOTO 480
460 B=0
470 C=POSI
480 POKE 789,C                    'Set Position of motor A
490 POKE 790,B
500 POKE 791,&H0
510 '
520 'example: Load SPEED register of both motors with 20 for a speed of:
530 '         .0001 x 20 = .0020 sec/step => 500 steps/sec=500(2.5A)/s '
540 PRINT " Scanning---5.00 A/sec"
550 PRINT "Other speed, see line 490, change lines of 610,620,3600"
560 POKE 768,&H88          'Set Speed of motor A, input 10000=5A/sec'
570 POKE 769,&H13
580 '
590 '  Load DISTANCE registers of A  motor in nm '
```

```
620 PRINT " "
630 PRINT "POSITION OR CHANGE LINE 3600"
640 PRINT " "
650 INPUT DIST
660 CLS
670 IF DIST <100 OR DIST >1080 GOTO 2460
680 DIST=DIST*4
690 IF DIST<256 GOTO  780
700 AA$=HEX$(DIST)
710 BB$=LEFT$(AA$,1)
720 CC$=RIGHT$(AA$,2)
730 BB$="&H"+BB$
740 CC$="&H"+CC$
750 BB=VAL(BB$)
760 CC=VAL(CC$)
770 GOTO 800
780 BB=0
790 CC=DIST
800 POKE 781,CC
810 POKE 782,BB
820 POKE 783,0
830 '
840 '
850 '  Set the EFSS registers of both motors to 100.  This will set the starting
860 '  speed of the motors to 100 x .0001 = .01 sec/step => 100 steps/sec
870 '
880 POKE 794,100               'Set EFSS of motor A
890 POKE 795,0
900 POKE 796,0
910 '  Set the STPFSS register  of the motor to 50.  This will set the ramp
920 '  length to 50 steps.
930 '
940 POKE 790,50                'Set Ramp length of motor A
950 '
960 '  Set the stepping mode of the  motor to HALF STEP.
970 '
980 POKE 801,1                 'Set Stepping mode of motor A
990 '
1000 '
1010 '  Place the MA (Move Absolute) command in the command buffer.
1020 '
1030 POKE 1020,ASC("M")
1040 POKE 1021,ASC("A")
1050 '
1060 '  Execute the MA command    '
1070 '
1080 POKE 1023,ASC("A")
1090 '
1100 '
1110 ' THE FOLLOWING PROGRAM IS FOR IBM DATA ACQUISITION BOARD
1120 '
1130 '.
1140 'LOAD HEADER FOR IBM DATA ACQUISITION CARD
1150 '
1160 '
1170 'NAME:  Data Acquisition And Control (DAAC)
1180 '       HEADER for BASICA
1190 '
1200 'FILE NAME:  DACHDR.BAS
1210 '
1220 'DOS DEVICE NAME:  DAAC1
1230 '
1240 'RESERVED FUNCTION NAMES:
1250 '            AINM, AINS, AINSC, AOUM, AOUS,
```

```
1280 'RESERVED DEF SEG VALUE NAME:  DSEG
1290 '
1300 'NAMES DEFINED AND USED BY HEADER:
1310 '          ADAPT%, AI, COUNT, FOUND%,
1320 '          HNAMES, SG%, STAT%
1330 '
1340 '
1350 'When using the BASICA Interpreter, this header
1360 'must be executed before any function calls are
1370 'made that access the DAAC adapter.  It initializes
1380 'a number of variables for each function call.  These
1390 'variables are reserved and should not be used except
1400 'to access the DAAC adapter.  This routine also does a
1410 'DEF SEG to the segment where the DAAC Device Driver
1420 '(DAC.COM) is loaded.  If you execute a DEF SEG to
1430 'access other hardware, you must    SEG to the segment
1440 'of the DAAC Device Driver before any subsequent
1450 'calls to access the DAAC adapter.
1460 '
1470 '
1480 FOUND% = 0
1490 SG% = &H2E
1500 'Start searching the interrupt vectors until you find
1510 'one that points to the DAAC device driver.
1520 'Do a DEF SEG to that segment.
1530 WHILE ((SG% <= &H3E) AND (FOUND% = 0))
1540       DEF SEG = 0
1550       DSEG = PEEK(SG%) + PEEK(SG% + 1) * 256
1560       DEF SEG = DSEG
1570       HNAMES=""
1580       FOR AI=10 TO 17
1590              HNAMES = HNAMES + CHR$(PEEK(AI))
1600       NEXT AI
1610       IF HNAMES = "DAAC    " AND PEEK(18) + PEEK(19) <> 0 THEN FOUND% = 1
1620       SG% = SG% + 4
1630 WEND
1640 IF FOUND% = 0 THEN PRINT "ERROR: DEVICE DRIVER DAC.COM NOT FOUND" : END
1650 'Now initialize all function name variables for calls
1660 'to access the device driver.
1670 AINM         = PEEK(&H13) * 256 + PEEK(&H12)
1680 AINS         = PEEK(&H15) * 256 + PEEK(&H14)
1690 AINSC        = PEEK(&H17) * 256 + PEEK(&H16)
1700 AOUM         = PEEK(&H19) * 256 + PEEK(&H18)
1710 AOUS         = PEEK(&H1B) * 256 + PEEK(&H1A)
1720 BINM         = PEEK(&H1D) * 256 + PEEK(&H1C)
1730 BINS         = PEEK(&H1F) * 256 + PEEK(&H1E)
1740 BITINS       = PEEK(&H21) * 256 + PEEK(&H20)
1750 BITOUS       = PEEK(&H23) * 256 + PEEK(&H22)
1760 BOUM         = PEEK(&H25) * 256 + PEEK(&H24)
1770 BOU.         = PEEK(&H27) * 256 + PEEK(&H26)
1780 CINM         = PEEK(&H29) * 256 + PEEK(&H28)
1790 CINS         = PEEK(&H2B) * 256 + PEEK(&H2A)
1800 CSET         = PEEK(&H2D) * 256 + PEEK(&H2C)
1810 DELAY        = PEEK(&H2F) * 256 + PEEK(&H2E)
1820 'Finally, execute any call to re-initialize the
1830 'device driver from any former invocation of BASIC.
1840 ADAPT% = 0
1850 COUNT = 1
1860 STAT% = 0
1870 CALL DELAY (ADAPT%, COUNT, STAT%)
1880 '
1890 'End of DAAC BASICA Header
1900 '
```

```
1940 'use on-board analog I/O device
1950 DEVICE% = 9
1960 'and DIMension a 640 point array
1970 '
1980 DIM RAWDATA%(639)
1990 '
2000 CLS
2010 RATE = 1000
2020 COUNT = 10
2030 '
2040 '**********************************
2050 'this program takes samples from
2060 'channel 3 of the on-board analog input device
2070 'and stores them in a one-dimensional array
2080 '
2090 'assign values to the arguments of AINM
2100 CHANNEL% = 3
2110 CTRL% = 0
2120 MODE% = 0
2130 STOR% = 0
2140 STAT% = 0
2150 '
2160 PRINT "Sampling analog input channel 3..."
2170 TMI= TIMER
2180 TMO = TMI
2190 FOR I= 1 TO IMAX
2200 TM = TIMER
2210 IF (TM-TMO) >= SAMTM1 GOTO 2230
2220 GOTO 2200
2230 CALL AINM (ADAPT%, DEVICE%, CHANNEL%, CTRL%, MODE%, STOR%, COUNT, RATE, RAW
DATA%(0), STAT%)
2240 'if status non-zero, set line and go to error handler
2250 IF STAT% <> 0 THEN LNUM% = 2310 : GOTO 2400
2260 TMO = TMO + SAMTM1
2270 T(I) = TM-TMI
2280 AVG = 0!
2290 FOR K = 0 TO 9
2300 AVG = AVG + RAWDATA%(K)
2310 NEXT K
2320 AVGDATA!(I) =INT (AVG/10!)
2330 KEY(1) ON
2340 ON KEY(1) GOSUB 2510 'for stopping the motion of the motor'
2350 NEXT I
2360 PRINT TMI,TM
2370 '
2380 GOTO 2590
2390 '
2400 '****** Error handler begins here *******
2410 '
2420 'on status error, print message, error number, and exit
2430 PRINT "Execution Error # ";STAT%; "in line number "; LNUM%
2440 PRINT "Program Terminated"
2450 END
2460 PRINT "EXCEED UPPER OR LOWER LIMIT , 100-1080 NM"
2470 GOTO 300
2480 '
2490 '
2500 '
2510 KEY (1) OFF
2520 DEF SEG=&HD000
2530 POKE 1020, ASC("S")
2540 POKE 1021, ASC("T")
2550 POKE 1023, ASC("A")
```

```
2590 'LOOP FOR CONVERTING DIGITAL VALUE TO MILLIVOLT'
2600 FOR I=1 TO IMAX
2610 VOLT(I)=(20/4096*AVGDATA!(I)-10)/100*SENSI*AMP
2620 NEXT I
2630 'LOOP FOR CONVERTING TIME TO WAVELENGTH & ENERGY'
2640 FOR I=1 TO IMAX
2650 WAVE(I)=POSI/4 -INT(T(I)*2)*.25
2660 IF CALI=1 THEN WAVE(I)=1.00237*WAVE(I)-.44212 'BLAZE-700 CALIBRATION'
2670            ELSE WAVE(I)=.9985*WAVE(I)+7.5212 'BLAZE-450 CALIBRATION
2680 ENG(I)=1239.5/WAVE(I)
2690 NEXT I
2700 OPEN FILE$ FOR OUTPUT AS #1
2710 FOR I=1 TO IMAX
2720 PRINT#1,USING"##.######^^^^   ";ENG(I),VOLT(I)
2730 NEXT I
2740 CLOSE#1
2750 END
```