Measurements in physical optics

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Date: 15.01.2019
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Contents

Abstract

Optics represents a very important and much researched field in applied as well as theoretical physics. Such an important field merits an high level of exposure to students. Study of wave phenomenon and particle nature is the basis upon which experiments on physical optics are built. This owes to the fact that light (and all electromagnetic radiations) exhibitdual nature - they behave as both particles and waves. We can perform experiments to study wave phenomenon such as interference, diffraction, polarisation, etc. By performing these experiments, we can infer a lot about the characteristics of the waves that make up electromagnetic radiation. We can also construct experiments which demonstrate the particle nature of elcetromagnetic radiation. Experiments involving photoelectric effect for light are used to study the particle nature. Certain experiments conducted on diffraction, polarisation and photoconductivity are of particular importance and will be focused upon by the authors so as to verify several laws relating to wave mechanics and particle nature of electromagnetic radiation.

Chapter 1

Introduction and motivation

I Photoconductivity

Photoconductivity is a phenomenon which is based upon the particle nature of light. Photo-conductivity occurs because light can be considered as packets of finite energy. When these packets interact with electrons, they are absorbed by the electron or are reflected by the electron resulting in an exchange of energy. When this exchange results in the increase in electron's energy, we have the electron go from the valence band to the conductive band and hence for the material to have an increase in its conductivity.
Photoconductivity is a very important which phenomenon which used in a lot of electronics. Devices such as solar panels use principles which are also applicable in photoconductivity and hence the study of photoconductivity can help in the understanding of this principles which then can be extended and applied to other phenomenon in elctronics and other fields

II Wave phenomena: diffraction and polarisation

Diffraction and polarization are both phenomenon which occur due to radiation possessing a wave nature and displaying wave characteristics. Diffraction is the phenomenon which occurs when light strikes an edge. This results in a sort of bending of light and we get finite intensity of light in regions where we expect zero itensity from classical ray optics. If we have multiple edges in close proximity to each other with light incident on them, the light waves will diffract from each of the edges and interfere with each other to give a more complex pattern (more complex than from simple addition of each edge). Polarization is also a wave phenomenon. Radiation is a transverse wave which has oscillations of electric field and magnetic field in a plane which is perpendicular to direction of propogation of the radiation. The phenomenon of restricting the direction of these oscillations is called polarization.
The study of wave phenomenon is very essential because many natural phenomenon and man made make use of these wave phenomenon. The wings of the butterfly are classic examples of diffraction in nature. The wings act as an grating which result in diffraction and are responsible for the colours of the wing. We use diffraction in the study of crystals. We can find parameters like distance between planes using diffraction. Polarization is used in sunglasses to reduce the intensity of light which is incident on the eyes. Such uses necessitate

the study of wave phenomenon.

III   Summary of experiments performed

1. To study and verify the intensity pattern due to diffraction which is formed on a screen when plane polarized laser light is passed through:-

   - An inductive grid (An array of square apertures).
   - A conductive grid (An array of opaque squares).

2. Determination of the diffraction pattern of the microwave intensity

   - behind the edge of a screeen.
   - after passing through a slit.
   - behind a slit of variable width, with a fixed receiving point.

3. To verify Mallus law and to study the elliptical polarization of light.

4. To study the Photoconductivity of **CdS** photo-resistor at constant irradiance and constant voltage

   - To plot the current- voltage characteristics at constant irradiance.
   - To measure photocurrent I_{Ph} as a function of irradiance ϕ at constant voltage.

Chapter 2

Experimental set-ups and relevant theory

I   Photoconductivity set-up

APPARATUS:

- Lamp Housing

- Adjustable slit

- Polarizer

- Analyzer

- Two convex lens

- Photo-resistor

- Multimeter

- Optical bench with fixing mounts

THEORY:

Photoconductivity is an optical and electrical phenomenon in which a material become more electrically conductive due to the absorption of electromagnetic radiation such as visible light, ultraviolet light, infrared light, or gamma radiations. is the effect of increasing electrical conductivity Φ in a solid due to light absorption. When the so-called internal photo effect takes place, the energy absorbed enables the transition of activator electrons into the conduction band and the charge exchange of traps with holes being created in the valence band. In the process, the number of charge carriers in the crystal lattice increases and as a result, the conductivity is enhanced.

When light is absorbed by a material such as a semiconductor, the number of free electrons and electron holes changes and raises its electrical conductivity. To cause excitation, the light that strikes the semiconductor must have enough energy to raise electrons across the band gap. When a photoconductive material is connected as part of a circuit, it functions as a resistor whose resistance depends on the light intensity. In this context the material is called a photoresistor. Fig.1 depicts the current flow in a photoresistor when exposed to light rays.
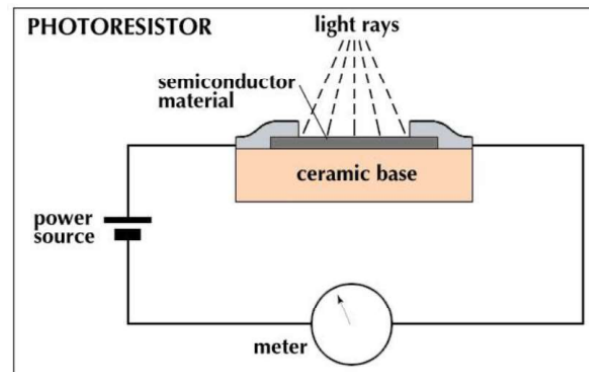
Semiconductor resistors that depend on the irradiance (photoconductive cells) are based on this principle. They have opened up a wide field of applications and are, among other things, employed in twilight switches and light meters. The semiconductor materials most commonly used are cadmium compounds, particularly CdS.

The photocurrent is studied as a function of the voltage applied to the photoresistor at a constant irradiance (current-voltage characteristics) and as a function of the irradiance at a constant voltage (current-irradiance characteristics).

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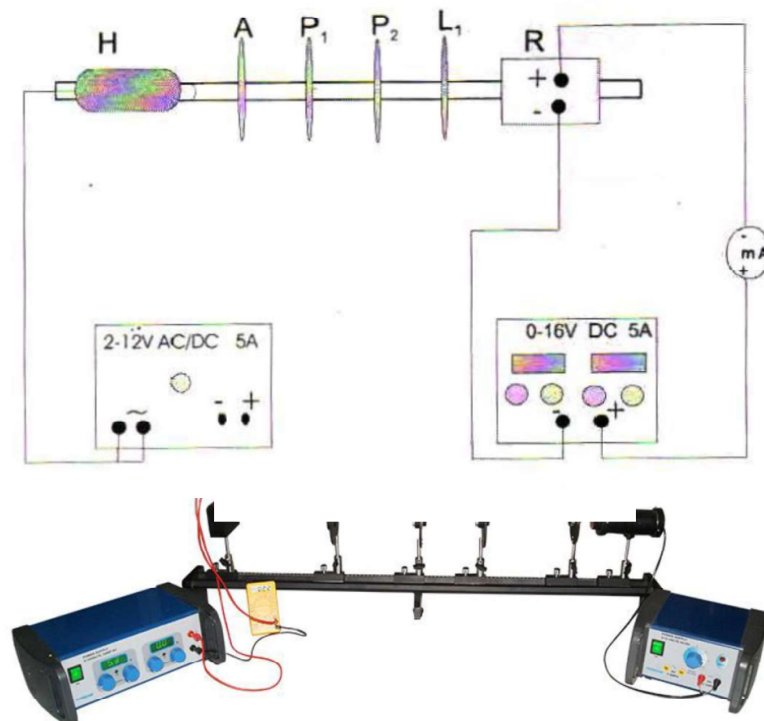
II Light diffraction set-up and the grids

APPARATUS:

- He-Ne Laser

- Conductive grid (array of opaque sqaures)

- Inductive grid (array of square apertures)

- Optical bench with suitable uprights.

- Laser detector with current measuring device.

(a) Inductive Grid

(b) Capacitive Grid
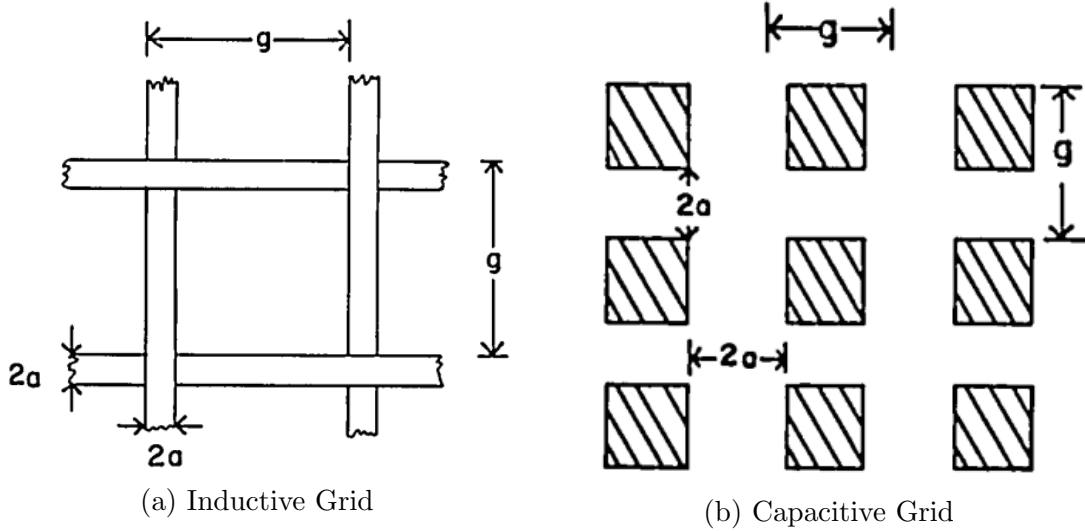
THEORY:

If we consider a to have a single square aperture with a side length 'a', we see that the itensity on the screen is given by:

$$I = I_0 sinc^2(\alpha) sinc^2(\beta)$$

where,
$\alpha = \frac{2\pi x a}{D\lambda}$
$\beta = \frac{2\pi y a}{D\lambda}$
D is distance of screen from square aperture.
λ is wavelength of light.

In our case, we have an array of square apertures which form a sort of a grid. For such an array of apertures, we will have to add the contributions from all the apertures. For an array we get

$$G(P) = \frac{1}{NM} sin(\alpha) sinc(\beta) * \{\sum_N \sum_M exp\{-i2\pi[(j-1)\delta_x + (l-1)\delta_y]\}\}$$

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where,

G(P) is the relative amplitude of diffraction pattern.

$\alpha = \pi[(1-k)/\lambda]a(sin(\theta_1) + sin(\theta_2))$

$\beta = \pi[(1-k)/\lambda]a(sin(\phi_1) + sin(\phi_2))$

$\delta_x = (a/\lambda)(sin(\theta_1) + sin(\theta_2))$

$\delta_y = (a/\lambda)(sin(\phi_1) + sin(\phi_2))$

$k = 2t/a$

N is the number of rows.

M is the number of columns.

2t is the distance between the adjacent parallel edges of two adjacent apertures.

We get Intensity $I = |G(P)|^2$. The function will have sharp peaks when $\pi\delta_x = m\pi$ and $\pi\delta_y = m\pi$, where m is an integer (Also assuming small diffraction angle).

From the above conditions we get

$$\Delta\theta|_{max} = \lambda/a$$

From the sinc function, we see that at $\alpha = n\pi$ and $\beta = n\pi$ we will get minimas.

$$\therefore \Delta\theta|_{min} = \lambda/2t$$

where $\Delta\theta|_{max}$ is the angular distance of the first sahrp peak from the central maxima and $\Delta\theta|_{min}$ is the angular distance of the first minima from the central maxima due to the sinc function.

We will also get minimas when $\pi\delta_x \neq m\pi$ and $\pi\delta_y \neq m\pi$ and $N\pi\delta_x = m\pi$ and $M\pi\delta_y = m\pi$, where m is an integer. Assuming small diffraction angle, we get

$$\Delta\theta|_{min} = \lambda/(Na)$$

and

$$\Delta\theta|_{min} = \lambda/(Ma)$$

All this has been done assuming that the side length 'a' is greater than the distance between two aperture edges '2t'.

III Diffraction of micro-waves: set-up

APPARATUS:

- Microwave transmitter w. klystron.

- Microwave receiving dipole

- Microwave power supply, 220V

- Screen, metal, 300X300 mm

- Multirange meter with amplifier

- Measuring tape

- Meter Scale

- Tripod base

- Barrel base

- right angle clamp

- Support rod

- G-Clamp

- Connecting cords

THEORY:

If a spherical wave with its origin at P strikes an obstacle at 0, the intensity at the point of observation P' is calculated from the Huygens' principle according to which eaxh point around the obstacle is the origin of a new spherical wave. The space is divided up into zones, commencing in the plane of the obstacel, so that the average distances from adjacent zones (Fresnel zones) to P' differ by $\lambda/2$ where λ is the wave-length. The radii of the zones, for small radii, using the symbols shown in Fig. 2, are aproximately given by:

$$r_n = \sqrt{R(1 - R/\alpha)\lambda}\sqrt{n}$$

As the zones interfere destructively because of the phase difference adopted, only about half the intensity of the innermost zone contributes to the total intensity at P'. The diffraction of microwaves at the edge of a screen, due to interference of the wave directly incident with the cylindrical wave produced at the edge, produces maxima and minima on a line which runs parallel to the screen. The total intensity, expressed as a function of the distance ρ from the edge of the screen to this line, is:

$$I = C'\Big[\{\int_{\omega}^{-\infty} \cos\frac{\pi}{2}n^2 dn\}^2 + \{\int_{\omega}^{-\infty} \sin\frac{\pi}{2}n^2 dn\}^2\Big]$$
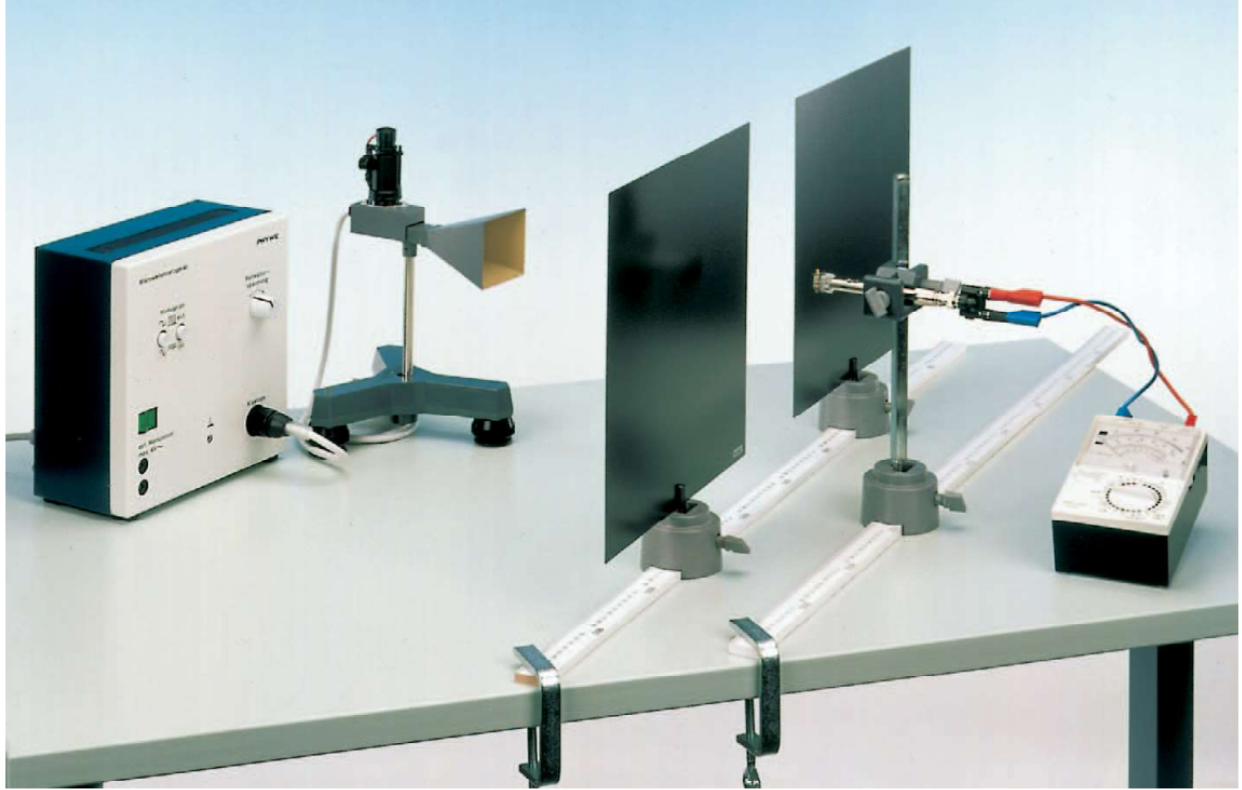
C' is a constant; the upper limit ω is given by:

$$\omega = \rho \frac{2}{\lambda} \left\{ \frac{1}{R_0} + \frac{1}{R} \right\}$$

$R_0 + R$ is the distance between the radiation source and the receiving point, R_0 and R being the respective distances between the plane of the screen and the source and the receiving point on the line connecting P and P'.

Maxima and minima occur if the difference r-s between (a) the distance and (b) the perpendicular distance between the receiving point and the edge of the screen satisfies the following condition:

$r - s = -(n + \frac{3}{8})\lambda$ maximum

$r - s = -(n + \frac{7}{8})\lambda$ minimum

where n is a whole number.
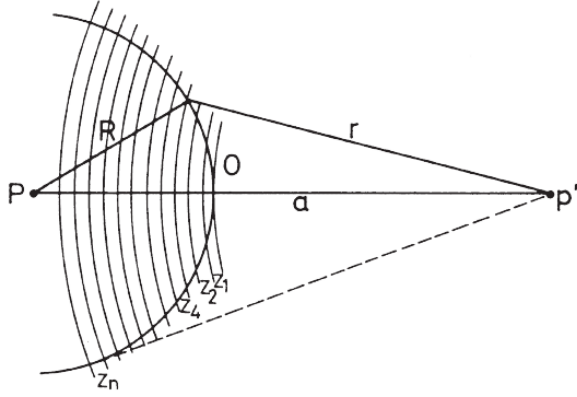
If a wave field impinges on a slit of width d, and if G(y) is the amplitude of the waves arriving at the slit, then a secondary wave is emitted from each point. If the primary waves arriving at the slit and the waves measured at P' can be regarded approximately as plane waves (Fraunhofer diffraction), the radiation intensity produced at P', by vectorial summation of all amplitudes, is:

$$I = \left\{ \int_c^d G(y) exp\left(i\frac{2\pi}{\lambda}y\sin\alpha\right)dy \right\}^2$$

where α is the receiving point angle. If G(y) is constant, this reduces to

$$I = \left(\frac{\sin\varepsilon}{\varepsilon}\right)^2$$

where

$$\varepsilon = \frac{\pi d}{\lambda}\sin\alpha$$

Minima for I are thus produced for

$$\sin\alpha = n\frac{\lambda}{d}$$

In order to obtain a minimum, d must be greater than or equal to λ, i.e. $d \geq \lambda$.

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IV   Polarisation set-up

APPARATUS:

- He-Ne Laser with inbuilt power supply.

- Polarizer

- Analyser

- Quarter Wave Plate

- Laser detector with current measuring device.

- Optivcal bench with suitable uprights.

Optic axis

Circular polarization out

Quarter-wave plate

Linear polarization in
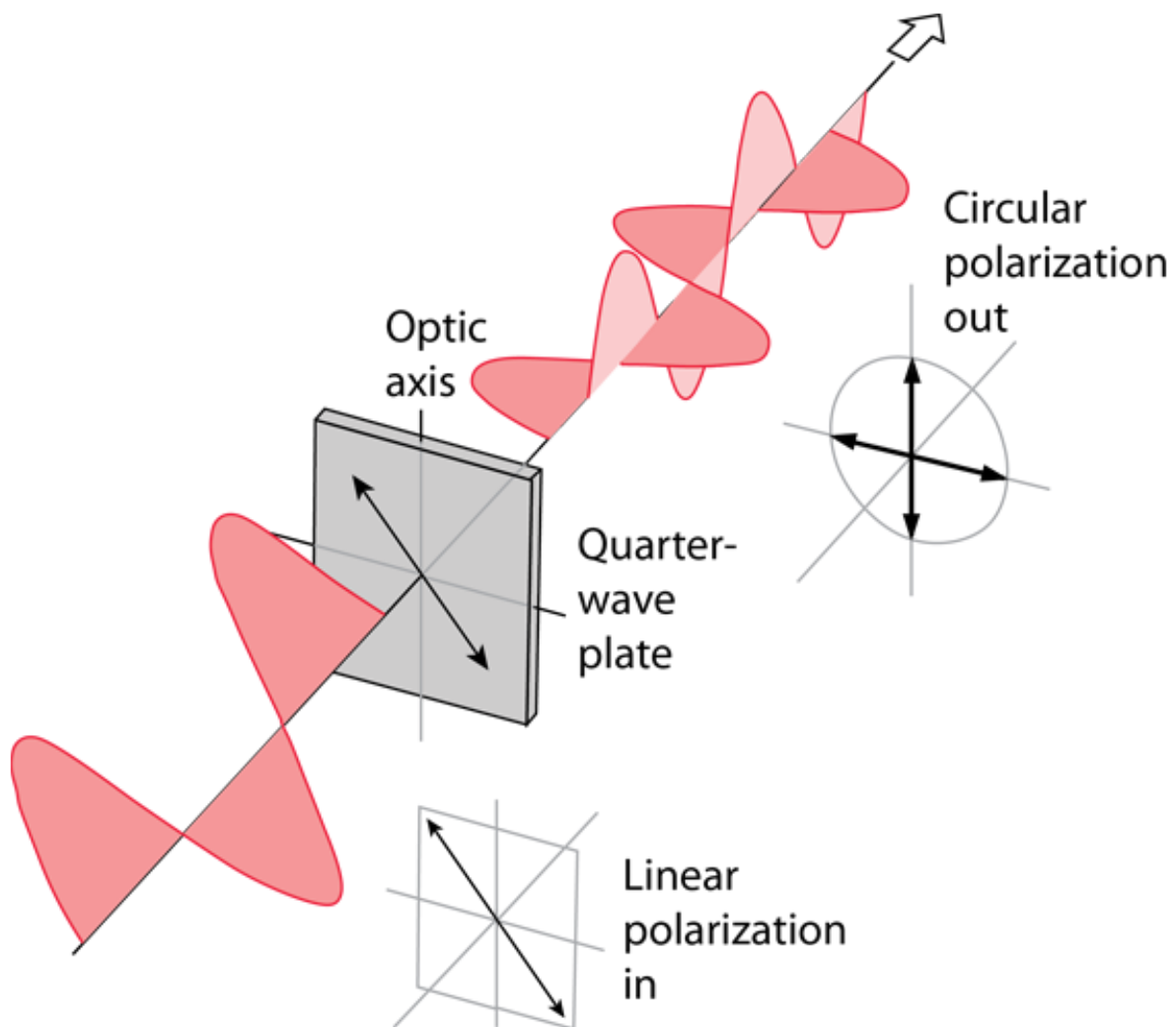
THEORY:

If the incident light is represented by

$$E = A\cos(wt - kz)$$

Then the two rays travel with different velocities through the quarter waveplate emerges with a relative phase difference $\delta = \pi/2$. So, the emergent rays are represented by

$$x = a\sin(wt - kz)$$

$$y = a\cos(wt - kz)$$

which forms an elliptically polarized light of the form

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

Now ,the intensity of light transmitted by the analyzer is

$$I = a^2\cos^2\theta + b^2\sin^2\theta$$

$$= (a^2 - b^2)\cos^2\theta + b^2$$

So, for $\theta = 0°$ and $\theta = 180°$

$$I = I_{max} = a^2$$

and for $\theta = 90°$ and $\theta = 270°$

$$I = I_{max} = b^2$$

Chapter 3

Experimental results and analysis

I Photoconductivity measurements

I.1 Current-Voltage characteristic at constant irradiance ϕ:

The relation between the photocurrent I_{Ph} and the voltage U applied at a constant irradiance (constant angle between the polarization planes of the filters), i.e. the current-voltage characteristics. Even at an angle $\alpha = 90°$ between the polarization planes of the filters a photocurrent flows, since in this position the polarization filters do not extinguish the ray of light completely.

Voltage (V)	Photocurrent (μA)			
	0°	30°	60°	90°
0	0	0	0	0.0
2	1.17	1.06	0.75	0.6
4	2.3	2.06	1.51	1.2
6	3.45	3.12	2.27	1.8
8	4.59	4.16	3.05	2.4
10	5.8	5.26	3.83	3.1
12	7	6.37	4.64	3.7
14	8.3	7.54	5.45	4.3
16	9.57	8.65	6.25	5.0

From the graph we obtain the slope of various current-voltage characteristics at different angles between the polarization planes of the filters (α). The slope gives the conductance of CdS Photoresistor at a particular irradiance.

Angle (α)	Conductance (μA/V)	Error (μA/V x10^{-3})
0°	0.5952	5.3
30°	0.5400	4.5
60°	0.3910	2.1
90°	0.3109	1.5

Current-Voltage characteristics of CdS Photoresistor
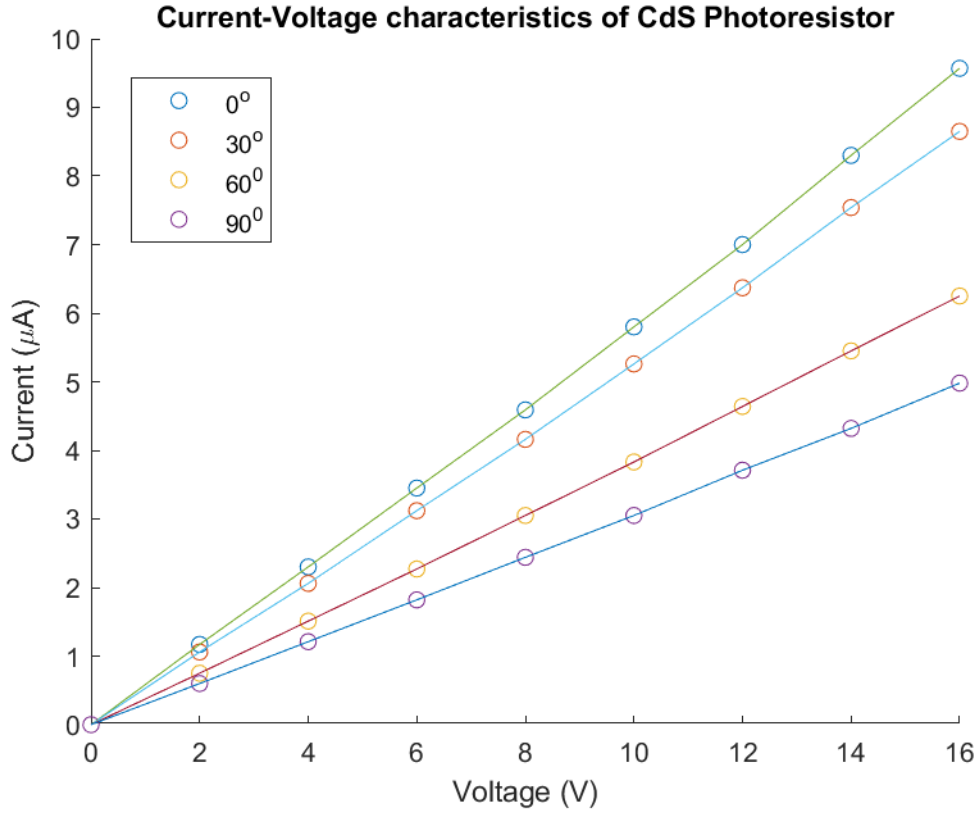
The CdS photoresistor behaves like an ohmic resistance that depends on the irradiance.

I.2 Current-Irradiance characteristics at constant voltage U:

The relation between the photocurrent I_{Ph} and the irradiance at a constant voltage, the current-irradiance characteristics. The term $cos^2(\alpha)$ is a relative measure for the irradiance (angle between the polarization planes of the filters). As expected, the photocurrent increases with increasing irradiance. However, the characteristics are not perfectly linear. The slope rather decreases with increasing irradiance.

$cos^2(\alpha)$	Photocurrent (μA)		
	1V	8V	16V
1.0	0.55	4.8	9.89
0.9	0.54	4.53	9.34
0.8	0.52	4.34	9.1
0.8	0.51	4.19	8.79
0.6	0.47	3.8	7.95
0.5	0.45	3.6	7.53
0.4	0.42	3.35	7.11
0.3	0.4	3.17	6.71
0.2	0.34	2.77	5.88
0.1	0.32	2.6	5.51
0.0	0.28	2.24	4.82
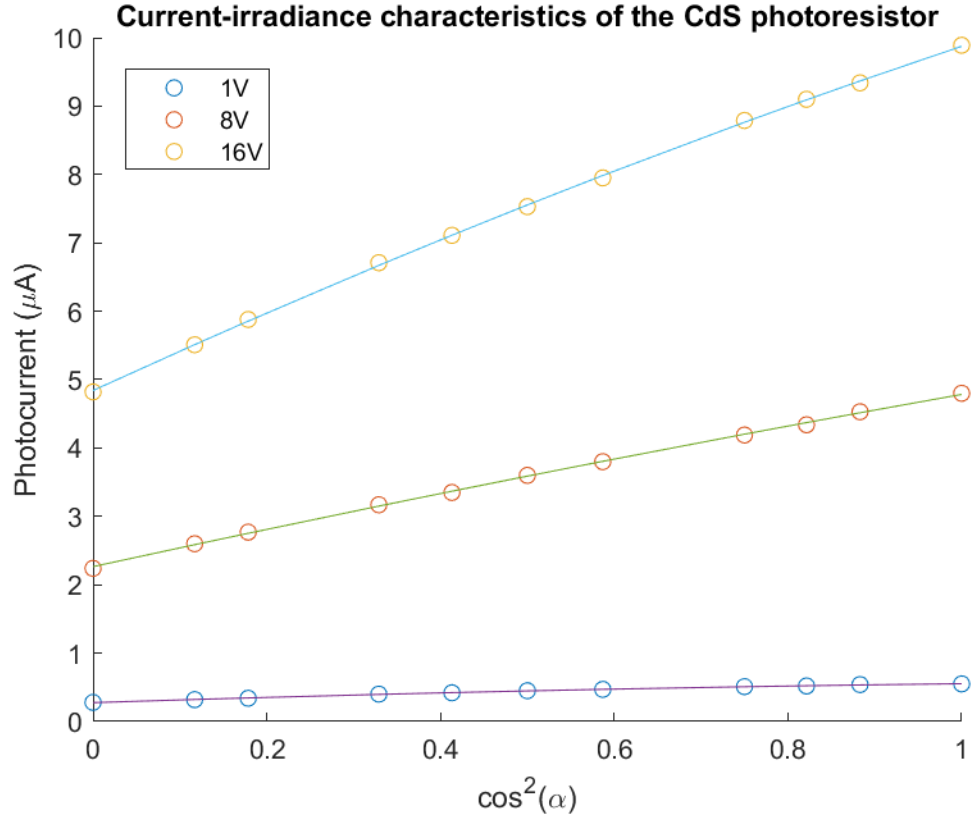
To capture the non-linear behavior of the curves we use a quadratic fitting.

$$f(x)=ax^2+bx+c$$

Voltage (V)	a (μA)	b (μA)	c (μA)
1V	-0.1319	0.4089	0.2761
8V	-0.2563	2.7749	2.2652
16V	-0.7859	5.8196	4.8414

II Measuring grating parameters using diffraction

Distance between slit and screen (D) = 108.8 cm

II.1 Inductive Grid

X-axis

X (cm)	Intensity (mA)	X (cm)	Intensity (mA)	X (cm)	Intensity (mA)
12	0.031	15.1	0.104	18.1	0.016
12.1	0.028	15.2	0.121	18.2	0.022
12.2	0.026	15.3	0.149	18.3	0.036
12.3	0.023	15.4	0.201	18.4	0.055
12.4	0.031	15.5	0.268	18.5	0.074
12.5	0.04	15.6	0.343	18.6	0.088
12.6	0.051	15.7	0.414	18.7	0.102
12.7	0.063	15.8	0.487	18.8	0.11
12.8	0.076	15.9	0.554	18.9	0.113
12.9	0.088	16	0.618	19	0.117
13	0.096	16.1	0.656	19.1	0.118
13.1	0.102	16.2	0.68	19.2	0.116
13.2	0.104	16.3	0.693	19.3	0.109
13.3	0.105	16.4	0.696	19.4	0.099
13.4	0.102	16.5	0.686	19.5	0.086
13.5	0.104	16.6	0.682	19.6	0.072
13.6	0.105	16.7	0.618	19.7	0.059
13.7	0.102	16.8	0.555	19.8	0.049
13.8	0.096	16.9	0.475	19.9	0.042
13.9	0.086	17	0.418	20	0.04
14	0.073	17.1	0.354	20.1	0.039
14.1	0.059	17.2	0.305	20.2	0.037
14.2	0.045	17.3	0.268	20.3	0.032
14.3	0.04	17.4	0.233	20.4	0.024
14.4	0.041	17.5	0.196	20.5	0.018
14.5	0.052	17.6	0.155	20.6	0.014
14.6	0.068	17.7	0.11	20.7	0.015
14.7	0.084	17.8	0.07	20.8	0.03
14.8	0.095	17.9	0.04	20.9	0.027
14.9	0.1	18	0.021	21	0.033
15	0.101				

Y-axis

Y (cm)	Intensity (μA)	Y (cm)	Intensity (μA)	Y (cm)	Intensity (μA)
4	26	7.4	122	10.7	36
4.1	26	7.5	118	10.8	67
4.2	23	7.6	112	10.9	92
4.3	27	7.7	123	11	114
4.4	32	7.8	151	11.1	116
4.5	37	7.9	206	11.2	112
4.6	40	8	266	11.3	104
4.7	39	8.1	350	11.4	98
4.8	37	8.2	431	11.5	100
4.9	31	8.3	494	11.6	98
5	26	8.4	548	11.7	101
5.1	24	8.5	591	11.8	102
5.2	27	8.6	623	11.9	100
5.3	34	8.7	651	12	95
5.4	50	8.8	670	12.1	88
5.5	69	8.9	675	12.2	81
5.6	87	9	666	12.3	74
5.7	104	9.1	645	12.4	67
5.8	114	9.2	612	12.5	61
5.9	121	9.3	573	12.6	51
6	128	9.4	522	12.7	43
6.1	132	9.5	470	12.8	35
6.2	133	9.6	429	12.9	27
6.3	130	9.7	387	13	20
6.4	123	9.8	343	13.1	14
6.5	111	9.9	298	13.2	11
6.6	97	10	244	13.3	10
6.7	83	10.1	185	13.4	13
6.8	73	10.2	127	13.5	22
6.9	71	10.3	75	13.6	32
7	79	10.4	34	13.7	42
7.1	93	10.5	14	13.8	44
7.2	108	10.6	17	13.9	47
7.3	119				
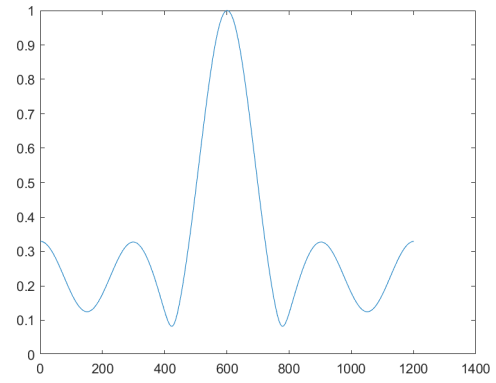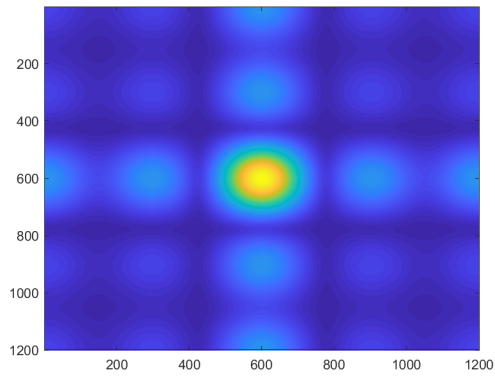
Computationally Reconstructed: 2D
Diffraction Image

Computationally Reconstructed:
Variation of Intensity along central axis.
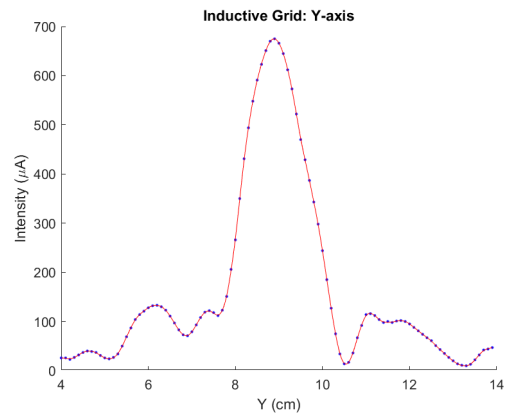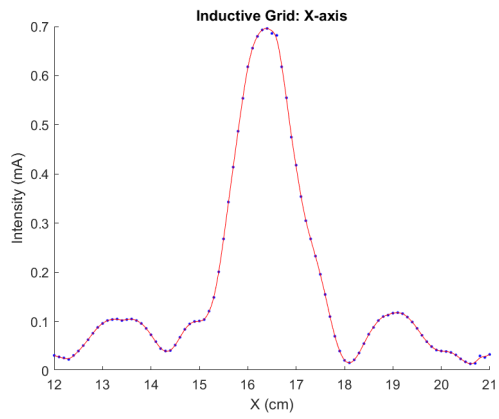
Variation of Intensity along X-axis

Variation of Intensity along Y-axis.

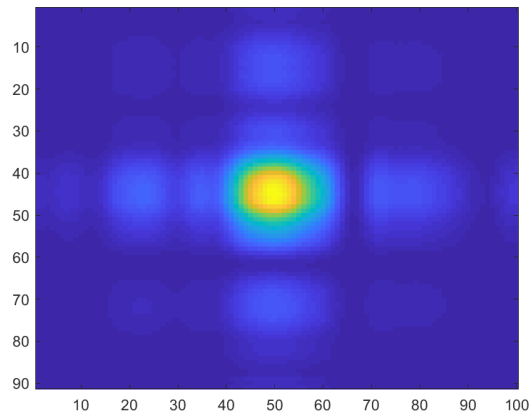2D Diffraction Image: Reconstructed using X
and Y components along central axis.

II.2   Capacitive Grid

X-axis

X (cm)	Intensity (μA)	X (cm)	Intensity (μA)	X (cm)	Intensity (μA)
12	69	15.1	156	18.1	71
12.1	69	15.2	238	18.2	71
12.2	65	15.3	325	18.3	68
12.3	59	15.4	416	18.4	67
12.4	55	15.5	522	18.5	72
12.5	53	15.6	614	18.6	88
12.6	57	15.7	729	18.7	111
12.7	65	15.8	837	18.8	132
12.8	80	15.9	954	18.9	147
12.9	91	16	1050	19	158
13	98	16.1	1150	19.1	163
13.1	105	16.2	1223	19.2	165
13.2	108	16.3	1259	19.3	161
13.3	110	16.4	1257	19.4	153
13.4	112	16.5	1193	19.5	142
13.5	112	16.6	1120	19.6	128
13.6	110	16.7	1038	19.7	109
13.7	107	16.8	957	19.8	90
13.8	101	16.9	885	19.9	70
13.9	93	17	798	20	58
14	88	17.1	703	20.1	52
14.1	84	17.2	580	20.2	52
14.2	83	17.3	467	20.3	52
14.3	80	17.4	330	20.4	51
14.4	75	17.5	237	20.5	47
14.5	64	17.6	153	20.6	40
14.6	48	17.7	99	20.7	31
14.7	35	17.8	73	20.8	23
14.8	34	17.9	68	20.9	19
14.9	53	18	66	21	21
15	94				

Y-axis

Y (cm)	Intensity (mA)	Y (cm)	Intensity (mA)	Y (cm)	Intensity (mA)
2.4	0.045	5.8	0.083	9.2	0.111
2.5	0.049	5.9	0.15	9.3	0.099
2.6	0.051	6	0.246	9.4	0.089
2.7	0.056	6.1	0.333	9.5	0.088
2.8	0.055	6.2	0.398	9.6	0.093
2.9	0.052	6.3	0.438	9.7	0.095
3	0.049	6.4	0.511	9.8	0.089
3.1	0.044	6.5	0.595	9.9	0.068
3.2	0.036	6.6	0.714	10	0.049
3.3	0.032	6.7	0.834	10.1	0.034
3.4	0.034	6.8	0.922	10.2	0.028
3.5	0.039	6.9	0.968	10.3	0.03
3.6	0.04	7	0.992	10.4	0.032
3.7	0.032	7.1	0.963	10.5	0.029
3.8	0.023	7.2	0.925	10.6	0.023
3.9	0.027	7.3	0.883	10.7	0.022
4	0.045	7.4	0.84	10.8	0.03
4.1	0.066	7.5	0.782	10.9	0.046
4.2	0.084	7.6	0.696	11	0.055
4.3	0.094	7.7	0.581	11.1	0.055
4.4	0.102	7.8	0.412	11.2	0.046
4.5	0.108	7.9	0.261	11.3	0.037
4.6	0.117	8	0.148	11.4	0.031
4.7	0.123	8.1	0.099	11.5	0.03
4.8	0.116	8.2	0.103	11.6	0.032
4.9	0.102	8.3	0.126	11.7	0.036
5	0.087	8.4	0.132	11.8	0.038
5.1	0.08	8.5	0.109	11.9	0.039
5.2	0.096	8.6	0.07	12	0.035
5.3	0.117	8.7	0.044		

Computationally Reconstructed: 2D
Diffraction Image

Computationally Reconstructed:
Variation of Intensity along central axis.
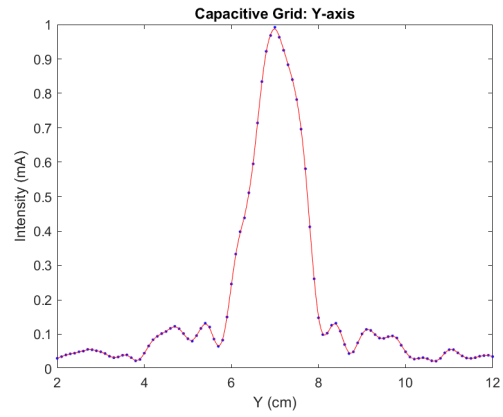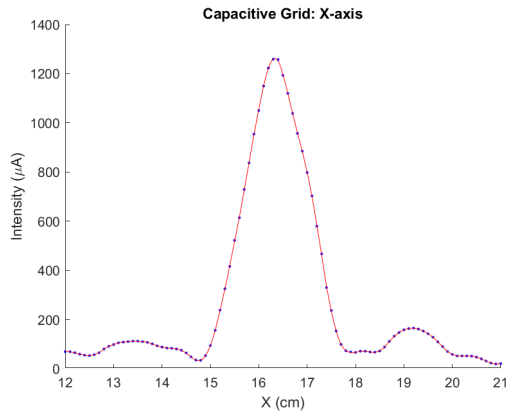
Variation of Intensity along X-axis

Variation of Intensity along Y-axis.

2D Diffraction Image: Reconstructed using X
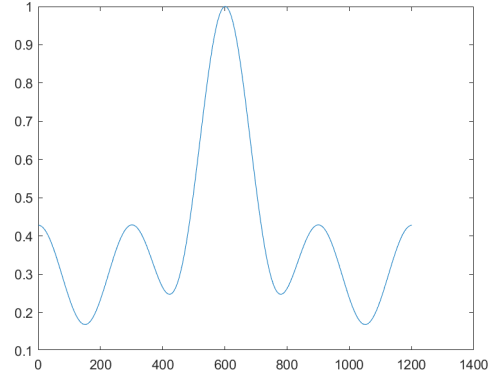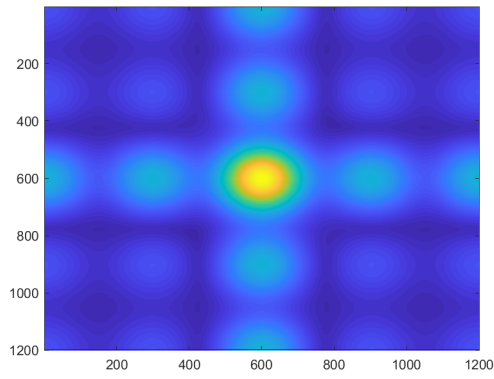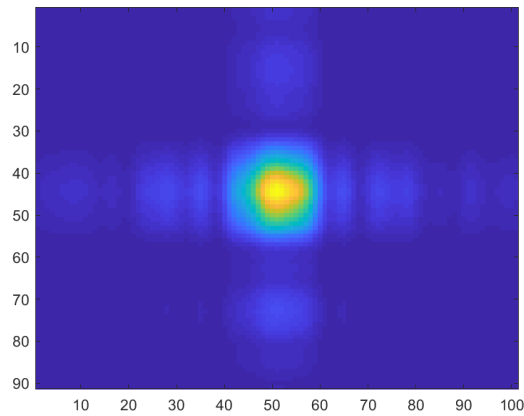and Y components along central axis.

III   Observing diffraction with microwaves

III.1 Diffraction of the Microwaves at the edge of a screen

X (cm)	Intensity (μA)	X (cm)	Intensity (μA)	X (cm)	Intensity (μA)
-200	1	-20	67	160	177
-190	5	-10	99	170	169
-180	2	0	144	180	134
-170	9	10	199	190	78
-160	8	20	272	200	44
-150	2	30	356	210	26
-140	0	40	418	220	27
-130	1	50	433	230	55
-120	5	60	445	240	80
-110	15	70	426	250	87
-100	16	80	383	260	82
-90	25	90	268	270	52
-80	37	100	170	280	29
-70	25	110	95	290	27
-60	35	120	68	300	38
-50	31	130	86	310	41
-40	41	140	108	320	42
-30	50	150	154	330	38

Intensity Distribution of Diffraction at the edge of a screen.

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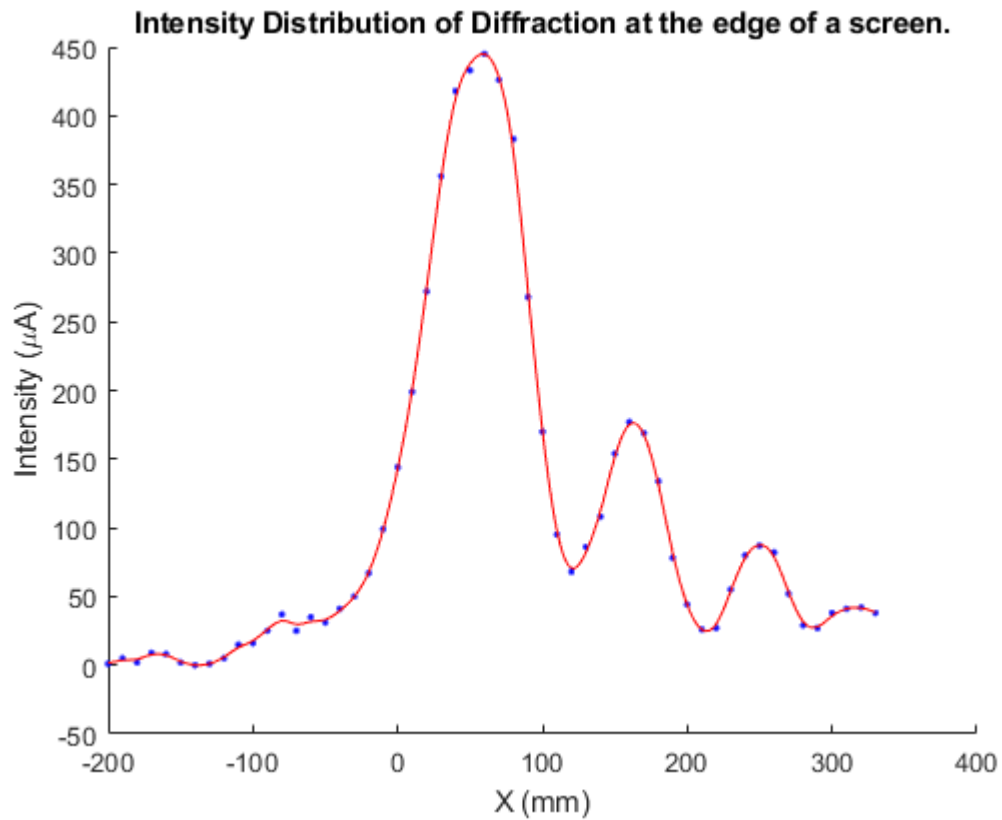
III.2 Diffraction of the Microwaves at the slit

X (cm)	Intensity (μA)	X (cm)	Intensity (μA)	X (cm)	Intensity (μA)
-300	7	-120	0	50	72
-290	6	-110	2	60	18
-280	3	-100	13	70	23
-270	3	-90	19	80	0
-260	1	-80	34	90	8
-250	5	-70	43	100	7
-240	4	-60	67	110	2
-230	9	-50	95	120	2
-220	14	-40	178	130	12
-210	8	-30	295	140	21
-200	7	-20	361	150	27
-190	2	-10	417	160	16
-180	8	0	503	170	7
-170	12	10	504	180	6
-160	15	20	427	190	14
-150	10	30	322	200	16
-140	6	40	198	210	15
-130	3				

Intensity Distribution of Diffraction at a slit.
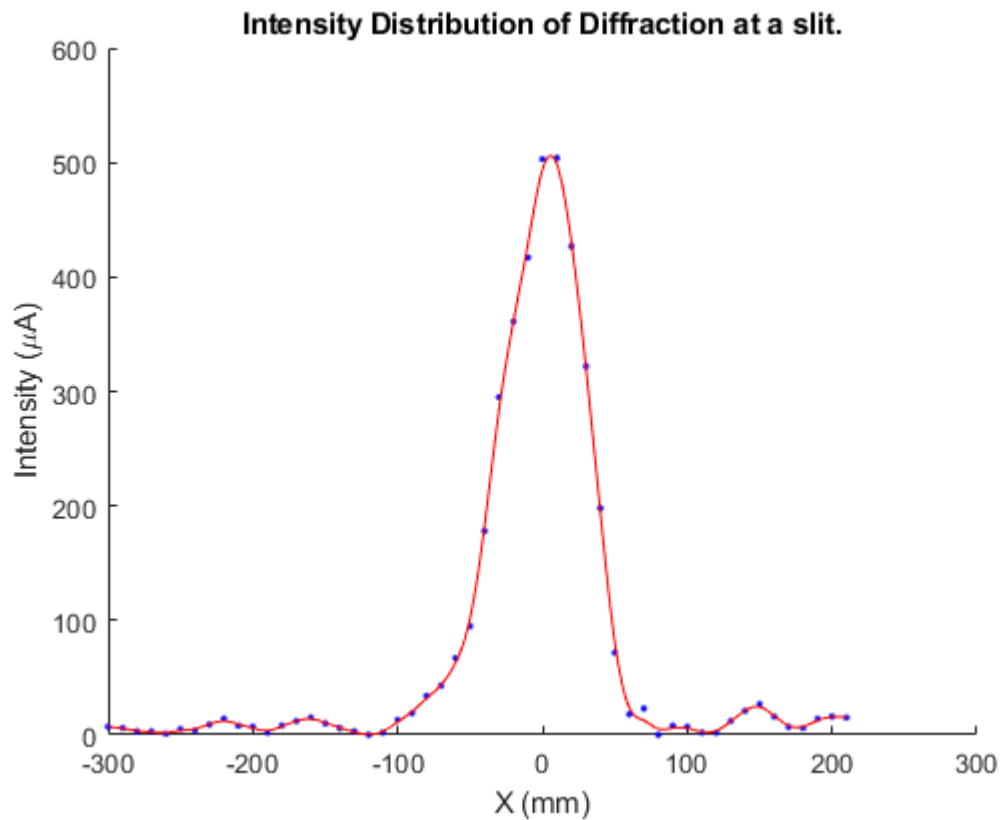
III.3 Diffraction of the Microwaves at the slit with varying slit width

D (cm)	Intensity (mA)	D (cm)	Intensity (mA)	D (cm)	Intensity (mA)
10	0.35	80	87.8	150	56.4
20	5.7	90	82.7	160	50.2
30	10.4	100	77.4	170	53
40	19.8	110	74.5	180	49.2
50	48	120	75.3	190	60.5
60	62.5	130	68.1	200	63.3
70	77	140	60.9		

Intensity Distribution of Diffraction at a slit as a function of slit width.
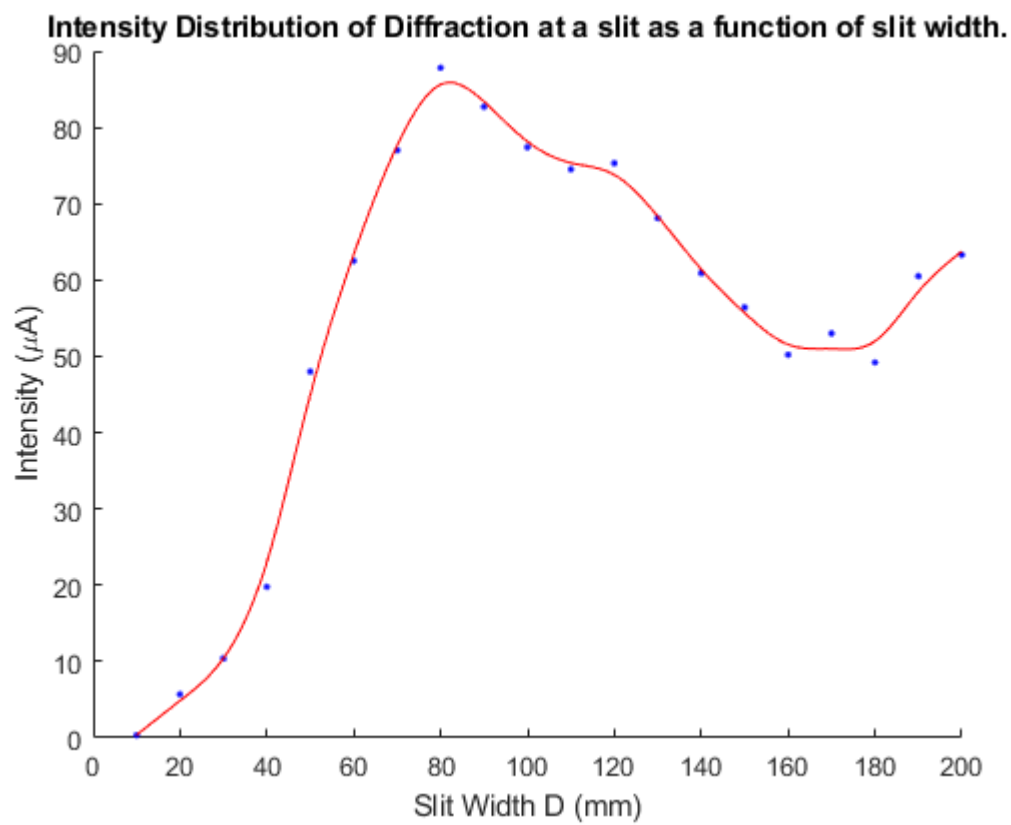
IV   Measuring polarization properties

Angle (degrees)	Photocurrent	$\cos(\theta)$	Angle (degrees)	Photocurrent	$\cos(\theta)$
0	17.7	1.00	185	19	-0.94
5	19.8	0.28	190	19.3	0.07
10	20	-0.84	195	19.1	0.98
15	20.2	-0.76	200	17.8	0.49
20	20.2	0.41	205	16	-0.70
25	19.9	0.99	210	16.5	-0.88
30	19	0.15	215	13.6	0.20
35	17.4	-0.90	220	12	1.00
40	15.2	-0.67	225	8.8	0.37
45	14.6	0.53	230	7	-0.79
50	9.9	0.96	235	6.8	-0.81
55	9.1	0.02	240	5.5	0.33
60	6.7	-0.95	245	3.9	1.00
65	4.6	-0.56	250	2.5	0.24
70	2.8	0.63	255	1.2	-0.86
75	1.7	0.92	260	0.6	-0.73
80	0.7	-0.11	265	0.1	0.45
85	0.2	-0.98	270	0	0.98
90	0	-0.45	275	0.2	0.11
95	0.1	0.73	280	0.7	-0.92
100	0.4	0.86	285	1.3	-0.63
105	0.9	-0.24	290	2.1	0.56
110	1.6	-1.00	295	2.5	0.95
115	2.4	-0.33	300	3.4	-0.02
120	3.5	0.81	305	5	-0.96
125	4.6	0.79	310	6.3	-0.53
130	6.8	-0.37	315	7	0.67
135	7.8	-1.00	320	8.2	0.90
140	9.5	-0.20	325	8.7	-0.15
145	11.2	0.88	330	9.4	-0.99
150	11.4	0.70	335	10.8	-0.41
155	11.2	-0.49	340	11.8	0.76
160	11.7	-0.98	345	13.6	0.84
165	13.5	-0.07	350	16.3	-0.28
170	16.1	0.94	355	16.6	-1.00
175	17	0.60	360	17.7	-0.28
180	17.7	-0.60			

The intensity of light transmitted by the analyzer is,
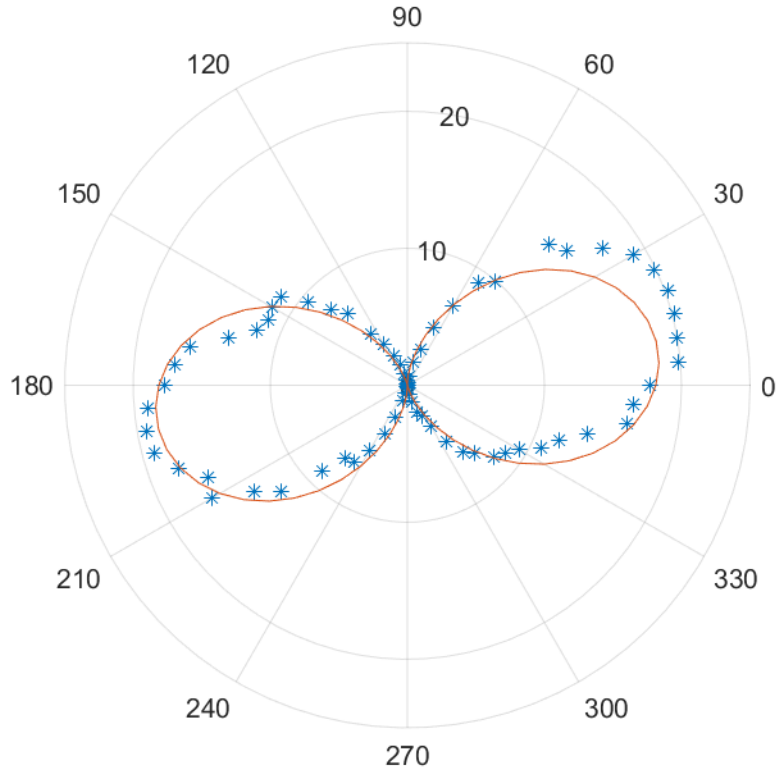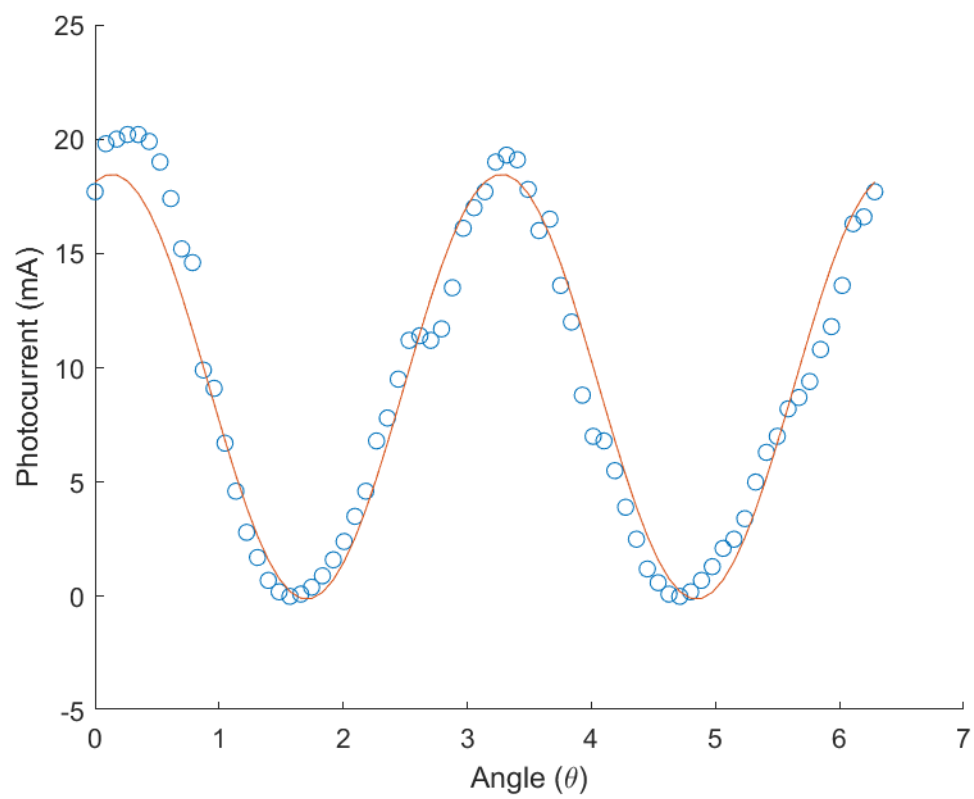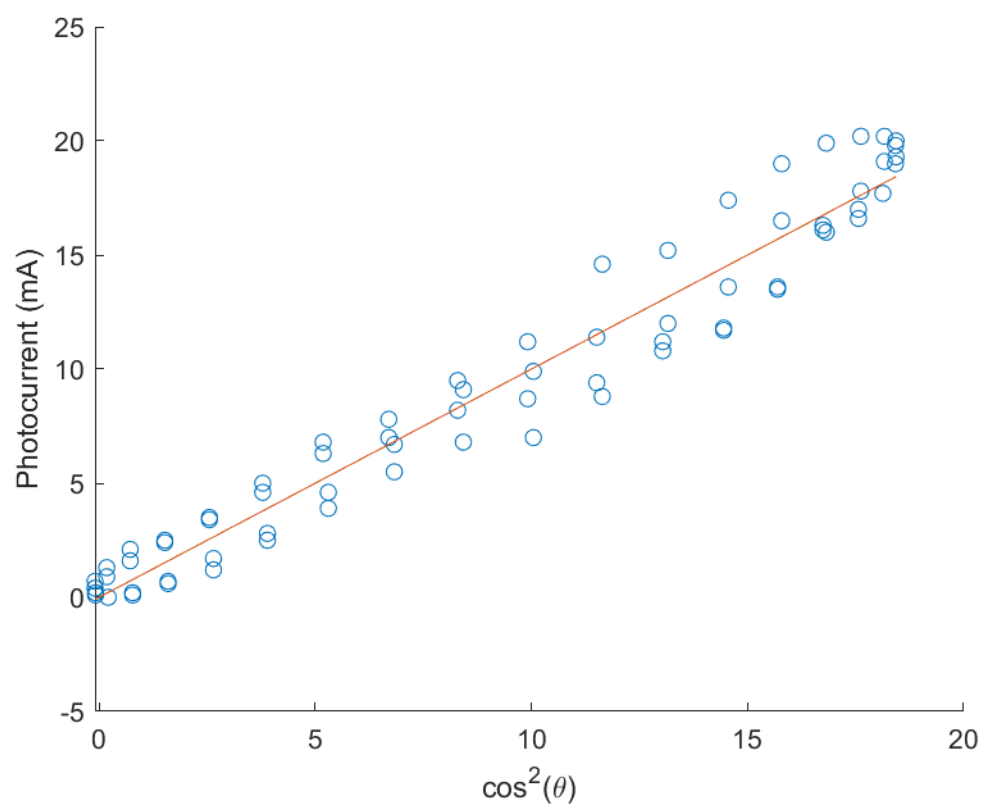
$$I = (a^2 - b^2)cos^2\theta + b^2$$

In the following analysis we have used parameter P1, P2, and P3 to fit the data.

$$I = P1 + P2 * cos^2(\theta - P3)$$

Comparing above two equations we have,

$$P1 = b^2, \; P2 = (a^2 - b^2)$$

Measurement of current for different orientation between analyzer and quarter wave plate

Angle	Photocurrent (μA)			Angle	Photocurrent (μA)		
	I	II	III		I	II	III
0	13.6	20.6	10.6	190	13.4	16.6	15.4
10	14.7	18.5	14	200	14.4	14.6	19.5
20	14.9	15.2	17.2	210	15.3	12.2	22.6
30	14.7	12.7	20.5	220	14.2	9.7	22.8
40	14.8	10.3	22.1	230	13.1	8.7	24.4
50	12.6	9.1	23.8	240	12.5	9.0	24.4
60	12.6	9.8	24.4	250	11.8	10.2	22.9
70	12.8	11.7	24.4	260	11.1	11.8	20.6
80	12.6	14.3	21.9	270	10.4	13.6	18.6
90	12.2	16.9	18.9	280	10	15.5	13.6
100	11.8	19.8	14.6	290	10.1	17.2	11.9
110	11.2	22.0	11.7	300	9.9	18.9	8.9
120	11.6	24.7	8.7	310	10.3	20.4	6.4
130	11.6	25.4	6.7	320	11.2	21.9	6.3
140	10.7	23.5	6.1	330	12.3	22.9	6.9
150	10.8	22.5	6.2	340	12.4	22.0	7.8
160	12.8	21.9	7.6	350	12.2	21.6	9.6
170	12.8	21.3	8.9	360	13.6	20.6	10.6
180	12.6	18.4	11.4				

Estimation of a/b

Setting	a^2-b^2	b^2	a/b
I	3.752	10.514	1.357
II	13.809	9.955	2.387
III	18.621	5.720	4.255

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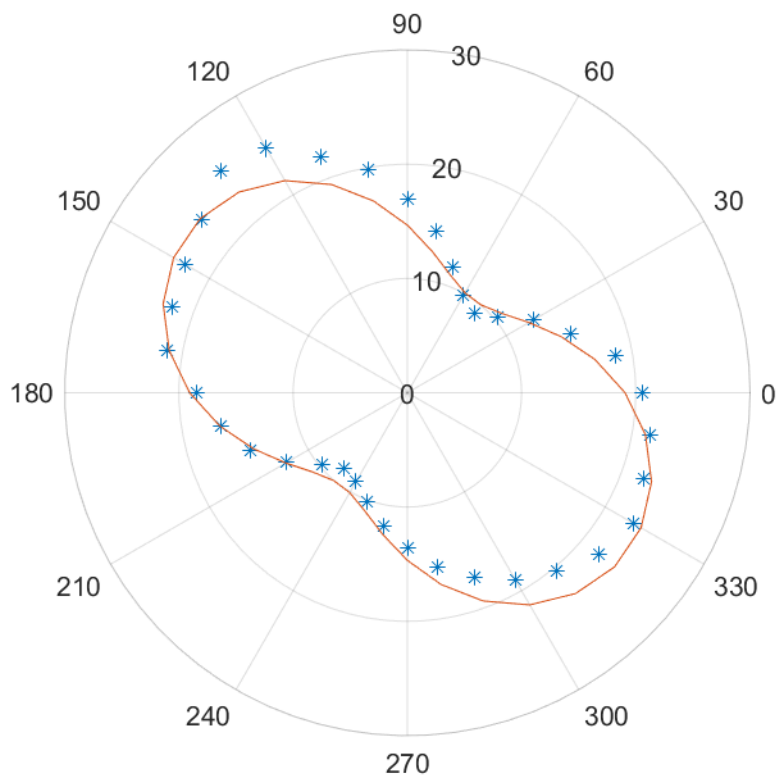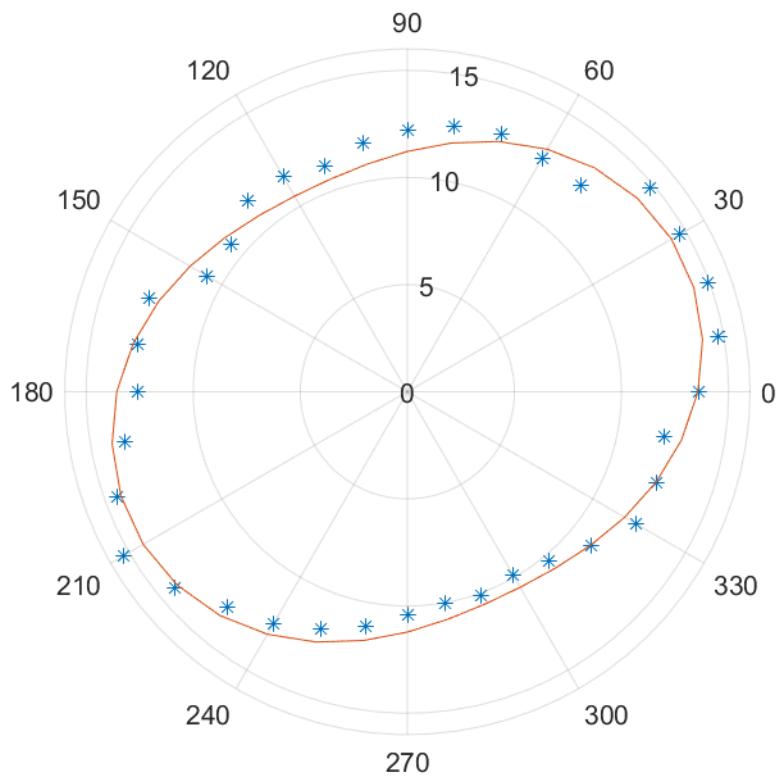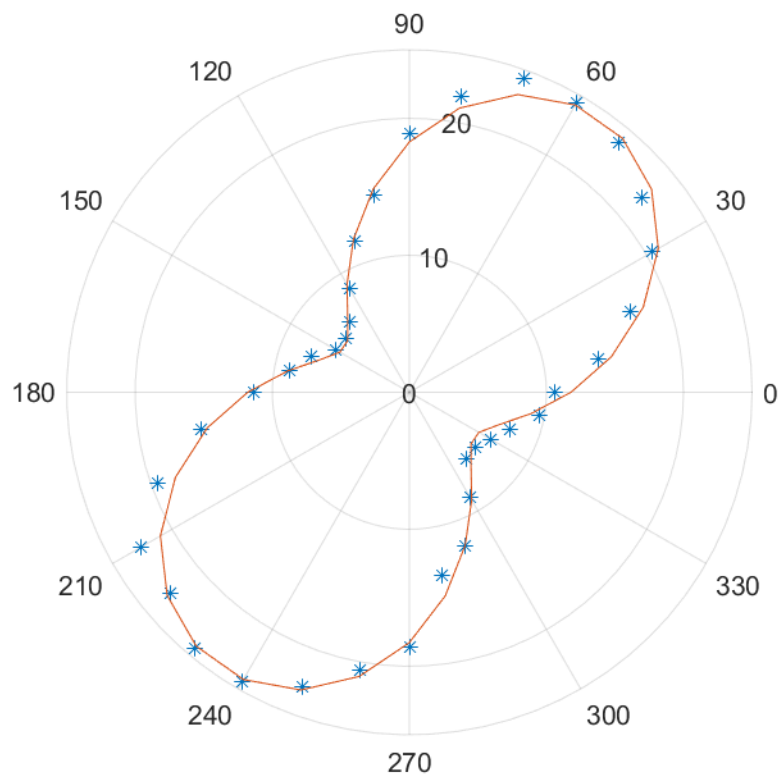
Chapter 4

Error analysis

I   Photoconductivity measurement

Current-Voltage characteristic of CdS Photoresistor
To compute the error in slope, we used the following formula,

$$\frac{\Sigma_{i=1}^{n}(y_i - y)^2}{(n-2)\Sigma_{i=1}^{n}(x_i - x)^2}$$

Error in Conductance at a particular irradiance.

Angle (α)	Conductance (μA/V)	Error (μA/V x10^{-3})	Percentage Error
0°	0.5952	5.3	0.89%
30°	0.5400	4.5	0.83%
60°	0.3910	2.1	0.54%
90°	0.3109	1.5	0.48%

Maximum statistical error in the conductance value is 0.89%.

Current-Irradiance characteristics of the CdS Photoresistor
The statistical error associated with the quadratic fitting is computed as following.

$$f(x) = ax^2 + bx + c$$
$$\Delta = \sqrt{\Sigma_{i=1}^{n}(f(x_i) - y_i)^2}$$

Voltage (V)	a (μA)	b (μA)	c (μA)	Error Δ (μA)
$1V$	-0.1319	0.4089	0.2761	0.0033
$8V$	-0.2563	2.7749	2.2652	0.0181
$16V$	-0.7859	5.8196	4.8414	0.0237

II   Diffraction

We do not require error analysis in case of Laser Diffraction and Diffraction of Microwaves because the analysis done is qualitative and the aim was to verify the general behavior of the functions.

III   Measuring polarization properties

The statistical error associated with the fitting of the following equation is computed.

$$I = P1 + P2 * cos^2(\theta - P3)$$

$$Error = \sqrt{\Sigma_{i=1}^{n}(I_{measured} - I_{fit})^2}$$

Setting	a^2-b^2	b^2	a/b	Error
Malus Law	18.584	≈ 0	∞	1.4605
I	3.752	10.514	1.357	0.6651
II	13.809	9.955	2.387	1.5019
III	18.621	5.720	4.255	0.7392

Chapter 5

Conclusion, discussion and remarks

I Laser Diffraction

Results

We can see that the data and the plots obtained from the data show somewhat similar characteristics as the theoretically expected results.

Precautions

1. We should take care to adjust the zero of the current measuring apparatus and also ensure that the background light intensity is minimum and non

2. We should ensure that the laser beam should be incident at a perpendicular angle on the inductive/ capacitive grid.

3. Source, aperture and Detector should lie along the optical axis.

4. At the beginning of the experiment the intensity at the central maxima is to be maximized by properly setting up the apparatus.

5. Background light intensity should be minimum and non fluctuating.

Sources of Error

1. Asymmetric illumination of square apertures by the laser.

2. Laser does not have constant intensity over the area of illumination.

3. Grids were not perfect squares in shape.

4. Physical vibrations were shaking the detector hence readings were affected.

Discussion

The intensity distribution obtained did not show proper maximas and minimas. We were expecting symmetrical behavior in the experimentally obtained intensity distribution as seen in the theoretical computation. Though the asymmetry could be accounted by the fact that in

theoretical computation we took some ideality assumptions like laser illuminates the square aperture in a symmetric fashion following a perfect Gaussian distribution whereas in reality the laser illuminates the slits in an asymmetric fashion.

Also in the computation we assume at the edges of the apertures/ opaque parts to be perfectly smooth, but in actuality they may have been rough which will result in a move away from ideal characteristics and may also cause asymmetry in the result obtained.

Computational Approach

Using Computational Methods we reconstructed the Diffraction image of the inductive and capacitive grids of an array of square opening. To carry on the computation we used concepts from Fourier Optics mainly the principle that states that Intensity distribution function obtained on the screen is a Fourier Transform of the Function of Intensity Distribution at the slit.

The first step is to simulate the Intensity Distribution Function (IDF) at the slit. Since in our case the IDF is an array of square aperture, we used digital function having 0's at the place of wire and 1's at the place of opening. Then we illuminated the center of the slit function using a laser function. To do this we assumed that the intensity distribution of laser follows a Gaussian distribution, i.e. the laser is brightest at the center and the intensity decays like a Gaussian around it.

As a final step we took the Fourier transform of this simulated IDF. To perform the fourier transform we employed the Fast Fourier Transform Algorithms which is used for performing Fourier Transform over discrete functions.

The computationally reconstructed images shows very close behavior to what we obtained experimentally.

Reconstruction of 2D Image To make a comparison between the computationally obtained data and experimental data, we reconstructed a 2D Image out of the 1D experimental data. We took the data experimentally across the central maxima along x-axis and y-axis. Then we used tensor dot product of the intensity data along the two axis to finally reconstruct the image.

$$I(x,y) = I_x(x) . I_y(y)$$

where '.' represents a tensor dot product.

II   Microwave Diffraction

Results

We see that the the nature plots obtained match well with the results from the functions obtained theoretically which we obtain theoretically.

Precautions

1. Source, Slit and Detector should lie along the optical axis.

2. Slits should be perpendicular to the optical axis.

3. We should ensure that the receiver is moved in a plane which is parallel to the plane in which the screen and the edges lie.

4. Physical movement should be minimized because microwaves have large wavelength and diffraction pattern gets affected by changes in the surrounding.

5. Intensity of Microwave is heavily fluctuating so before noting the reading one should wait for ample amount of time and observe the mean about which it fluctuates.

6. Distance between the source and slit is a crucial factor in this experiment. The distance should neither be too far else the intensity of the microwave at the detector will be too low, nor it should be too close else the expected fringe pattern will not be observed.

Sources of Error

1. Intensity of Microwave coming from the source was heavily fluctuating so the apparent least count was increased by an order of magnitude.

2. Since microwaves have large wavelength, the rays getting reflected from nearby walls were also interfering with the rays from the slit.

3. Mobile and telecommunication devices use microwaves for transmission. There were numerous such devices in the surrounding which were interfering with the microwaves coming from the source.

Discussion

The first time the experiment was done, there was a funnel attached at the receiver which resulted in inaccuracy in the experiment. This could have been because we were getting the average intensity of a range of points instead of at the exact point where the receiver was located. Also since the mouth of the funnel had a side length in the same order of magnitude as the wavelength of the microwaves, there could have been diffraction taking place at the sides of the funnel attached resulting in a change in intensity obtained.
We had to redo the experiment a number of times with varying distances of the source from the slits/ edge to finally get perfect results.
There was a lot of random fluctuation in the reading obtained from the receiver.
The position of people and objects around the setup also had an effect on the readings obtained. This may be because the objects might have reflected some of the microwaves and

sent it towards the receiver resulting in the increase in the readings

III Polarization

Results

Malus law is confirmed by the plot obtained from the first part of the experiment.

Precautions

1. Care should be taken that the angle between the plane of polarization of the polarizer and the optic axis of quarter wave plate is not 0° or 90° or 180° because at these angles, the waveplate will not behave like a uniaxial material.

2. We should ensure that the polarizer, the analyzer and the quarter wave plate are centered along the optical axis to get maximum efficiency from the set up.

3. We should take care to adjust the zero of the current measuring apparatus and also ensure that the background light intensity is minimum and non fluctuating.

Sources of Error

1. Laser source was itself polarized. Hence, the intensity obtained depended on the angle of the polarizer instead of it being only dependent on the angle between the polarizer and the analyzer.

Discussion

Getting Circular Polarization by setting the Quarter Wave Plate at an angle of 45° was difficult. As I already mentioned in the sources of error that that laser source was itself polarized so the output that we were getting out of the Polarizer was perfectly obeying the Malus Law. Hence we did not get expected circular polarization at 45°. The value of a/b should be exact 1 for circular polarization whereas what we obtained was 1.357 which is more like Elliptical Polarization.

Non-Linear Curve Fitting The analysis of the experiment demanded non-linear fitting of the data points on the curve,

$$I = P1 + P2 * cos^2(\theta - P3)$$

To obtain such a fitting I made use of lsqcurve fit function that is in-build in MATLAB. You can refer the codes by following the link given in the bibliography.

IV   Photoconductivity

Results

We see that the relation between the photocurrent I_{Ph} and the voltage U applied at a constant irradiance (constant angle between the polarization planes of the filters) shows a linear behavior. This shows that the material obeys Ohm's Law in the voltage range in which we operate. Even at an angle $\alpha = 90°$ between the polarization planes of the filters a photocurrent flows since the material will have some intrinsic non zero conductivity.

At $\theta = 0°$, Conductance $= 0.5952 \pm 5.3$ X $10^{-3}\mu$A/V

At $\theta = 30°$, Conductance $= 0.5400 \pm 4.5$ X $10^{-3}\mu$A/V

At $\theta = 60°$, Conductance $= 0.3910 \pm 2.1$ X $10^{-3}\mu$A/V

At $\theta = 90°$, Conductance $= 0.3109 \pm 1.5$ X $10^{-3}\mu$A/V

The relation between the photocurrent I_{Ph} and the irradiance ϕ at a constant voltage, the current-irradiance characteristics. The term $cos^2(\alpha)$ is a relative measure for the irradiance (angle between the polarization planes of the filters). As expected, the photocurrent increases with increasing irradiance. We expect the line to be a straight line but according to Malus law. However, the characteristics are not perfectly linear. The slope rather decreases with increasing irradiance. This maybe attributed to the fact that even though the number of photons emmitted by the source is directly proportional to the irradiance, the number of electrons which gain enough electron to enter the conduction band is not proportional to the intensity since all photons do not provide enough energy to the electron they interact with it to let them escape to the conduction band.

Precautions

1. We should ensure that the photoresistor should lie on the focal plane of the focusing lens.

Sources of Error

1. Background illumination

2. Inefficiency of polarizers

3. The initial light was polarised so the intensity of light changed with the angle of the polarizer.

Discussion

Photodetectors are made up of semiconductors. When light is absorbed by them the number of free electrons and holes changes and raises its electrical conductivity. So we expect that with increase in the irradiance of light the photocurrent will increase which is what we obtain experimentally. This increase in photocurrent is not linear because efficiency of Photodetectors decreases as the intensity of light is increases.

When the polarization planes of the filters were at $90°$ there was still a non zero intensity of light which was being received by the photoresistor which resulted in a greater than expected reading. This may have been due to inefficiency of the filters. Moreover we know that Photodetectors are combination of doped semiconductors connected in reverse bias configuration.

So, even if the intensity of light is turned zero by covering the detector with something we get some small photocurrent.

To analyze these expected behavior, we performed quadratic fitting on the data points. The intercept term in the fit represents the current at zero illumination, the coefficient associated with linear power captures the general trend of increase in photocurrent with increasing irradiance, and the coefficient associated with the quadratic term captures the decrease in the efficiency of detector with increasing irradiance.

Bibliography

- Optics - Ajoy Ghatak

- Fundamentals of Optics - Jenkins and White.

- https://github.com/vinitX/EMO_Lab.