Diffraction gratings for the Experimental study
by using a *CCD camera*

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Abstract

The capability of a biconvex lens in performing Fourier transformation . As a result of this capability one can work in the spatial   frequency domain to achieve filtering process . Consequently there are potential possibilities to use the previous capability in processing the recorded image in addition to a real time processing . Hence there are potential applications in processing the optical data in the fields of astronomy , microscopy , medical imaging , crystallography , and pattern recognition .

Two types of digital cameras have been utilized to record the experimental results , one of them an ordinary HD camera with (12 Mega Pixels) resolution and the other one is a CCD camera to record the power distribution of the Fourier transform in the spatial frequency domain . Good agreement is obtained between experimental and numerical results.

1- Introduction

The effect of diffraction is a general characteristic of wave phenomena occurring whenever a portion of a wave front , be it sound , a matter wave, or light, is obstructed in some way. The various segments of the wave front that propagate beyond the obstacle interfere, causing the particular energy-density distribution referred to as the diffraction pattern [1]. Fraunhofer diffraction deals with the limiting cases where the light approaching the diffracting object is parallel and monochromatic, and where the image plane is at a distance large compared to the size of the diffracting object [5] . The diffraction grating is of considerable importance in spectroscopy, due to its ability to separate (disperse) polychromatic light into its constituent monochromatic components [6] . Diffraction phenomena can be grossly classified into two types , namely : Fresnel and Fraunhofer , of these two, the Fresnel or near-field diffraction is relatively more complicated than the Fraunhofer, or far-field   diffraction .   No   exact analytical solution of Fresnel diffraction can be found even in the simplest cases [7-8].

2-History of Grating development

The first diffraction grating was made by an American astronomer,
David Rittenhouse, in 1785, who reported constructing a half-inch wide grating with fifty-three apertures. In 1821, Joseph von Fraunhofer began his work on diffraction gratings . By 1850, F.A. Nobert, a Prussian instrument maker, began to supply scientists with gratings superior to Fraunhofer's. About 1870, the scene of grating development returned to America , where L.M. Rutherfurd, a New York lawyer with an avid interest in astronomy, became interested in gratings.   In 1947, Bausch & Lomb decided to make precision gratings available   commercially. In 1950, through the encouragement of Prof. George R. Harrison of MIT, David Richardson and Robert Wiley of Bausch & Lomb succeeded in producing their first high quality grating. In 1985, Milton Roy Company acquired Bausch & Lomb's gratings and spectrometer operations, and in 1995 sold these operations to Life Sciences International plc as part of Spectronic Instruments , Inc. In 1997, Spectronic Instruments was acquired by Thermo Electron Corporation, and the gratings operation is now a separate business called Thermo RGL[9]. Diffraction grating components can be used for high quality bi-directional links. For mono-directional or bi-directional links they have virtually unlimited numbers of channels and provide the lowest crosstalk for the higher number of channels. For low cost mass production the problems of fiber handling, that are the same with any solution, remain to be solved [10].

3- Theory

A diffraction grating is a collection of reflecting (or transmitting)   elements separated by a distance comparable to the wavelength of light under study .
A reflection grating consists of a grating superimposed on a reflective surface, whereas a transmission grating consists of a grating superimposed on a transparent surface [4] . Diffraction gratings are often analyzed and synthesized by using Fresnel and Fraunhofer approximations. Some major application areas for diffraction gratings are spectroscopy, spectroscopic imaging, optical communications, and networking . A diffraction grating is an optical device that periodically modulates the amplitude or the phase of an incident wave . Both the amplitude and the phase may also be modulated . An array of alternating opaque and transparent regions is called a transmission amplitude grating . Such a grating is shown in Figures (1) and (2) .
If the entire grating is transparent, but varies periodically in optical thickness, it is called a transmission phase grating. A reflective material with periodic surface relief also produces distinct phase relationships

upon reflection of a wave. These are known as reflection phase gratings. Reflecting diffraction gratings can also be generated by fabricating periodically ruled thin films of aluminum evaporated on a glass substrate. Diffraction gratings are very effective to separate a wave into different wavelengths with high resolution. In the simplest case, a grating can be considered as a large number of parallel, closely spaced slits. Regardless of the number of slits, the peak intensity occurs at diffraction angles governed by the following grating equation [9]:-

$$d \sin \phi_m = m\lambda \qquad \text{..............(1)}$$

is the diffraction where d is the spacing between the slits , m is an integer called diffraction order , and angle. Equation (1) shows that waves at different (ϕ) wavelengths travel in different directions . The peak intensity at each wavelength depends on the number of slits in the grating . The phase of the incident wave can be modulated by periodically varying the thickness or the refractive index of a transparent plate[4] .

4-Observation of the diffraction pattern

Fraunhofer diffraction is only observed if the distance between the diffracting object and the observer is large compared to the wavelength. This criterion is satisfied for a screen which is some tens of centimeters from the diffracting object. However, if one wishes to use a charge coupled device (CCD) camera to record the measured diffraction, the limited size of the CCD requires that the camera needs to be placed closer to the object. The way around this problem is to use a convex lens .The diffracted beams leaving the grating are essentially parallel beams and so will be focused the distance (f) from the lens .
The lens has shifted the position of the diffraction pattern from infinity to the focal plane and resets the Fraunhofer condition for diffraction [3].

5-The Single Slit

The diffraction on a single slit is important because it is a simple one dimensional diffraction problem and appears in the diffraction pattern of all types of gratings and in other diffraction related phenomena [3] . The Fraunhofer diffraction pattern is generated at the back focal plane of a lens placed against the grating [2].
The intensity at point (p) on the screen is given by [1] :-

$$I(\theta) = I(0) \left(\frac{\sin \beta}{\beta}\right)^2 \qquad \text{......}(2)$$

shows the amplitude and intensity of the diffraction pattern observed
from a single slit. The first minimum occurs when light from an element in the upper half of the slit is out of phase with that from the corresponding element *(a/2)* away in the lower half, and they cancel . All elements can be paired in this way and thus the net effect is zero [1].

6- The Double Slit

Wavefronts are obstructed everywhere except at the slits , when we looked at two slit obstruction of a wave front previously we assumed that the apertures (slits) were point sources . In reality, we must take into account the finite size of the slits and for the double slit diffraction [2] :

$$I(\theta) = 4I(0)\cos^2(\alpha)\left(\frac{\sin \beta}{\beta}\right)^2 \qquad \text{.....}(3)$$

This equation shows that the intensity is 4 times (in the center maximum) that of a single slit .Where : -

$$\alpha = \frac{\pi d \sin \theta}{\lambda} \qquad \text{..... } (4)$$

λ = is the wavelength of the light and (d) is the distance between the slits . In the $(\theta = 0)$ direction (i.e.,

when $\beta = \alpha = 0$) , $I(0)$ is the flux density contribution from either slit , and $I(\theta) = 4I(0)$ is the total

flux density . The factor of (4) comes from the fact that the amplitude of the electric field is twice what it would be at that point with one slit covered [1] .

7-Multiple Slit Diffraction

The procedure for obtaining the irradiance function for a monochromatic wave diffracted by many slits is essentially the same as that used when considering two slits , combination of previous methods yields (for N identical equally spaced slits) , so the flux density distribution function is given by [2] :-

$$I(\theta) = I(0) \left(\frac{\sin N\alpha}{\sin \alpha} \right)^2 \left(\frac{\sin \beta}{\beta} \right)^2 \qquad ......(5)$$

From this equation we notice that $I(0)$ is the flux density in the $(\theta=0)$ direction emitted by any one of the slits and that $\{ I(\theta) = N^2 I(0) \}$ [2] .

The mathematical proof is not required for our purposes it is only   necessary   to   note   that   the   resulting diffraction   pattern   is   the   convolution   of   the diffraction pattern due to a single slit and the pattern due to two slits .
 there is an inverse relationship between the width/spacing of the slits and the width of the associated diffraction pattern [3] .

8-Experimental results

Lenses have both a front focal point and a back focal point (plane) our eyes also have a front focal point (usually250mm) move your hand towards your eyes and at some point your hand will go out of focus, it therefore follows that all object must be placed in front of the focal point of the lens if they are to be in focus in the final image [9]. This is illustrated in the laser diagram in figure (3). Just as a lens has a front focal point it also has a back focal point that is positioned behind the lens at the same distance as the front focal point and it is this back focal point which enables us to view the wavelengths from our object in the form of a diffraction pattern .

9- Conclusion

In conclusion , we have presented a simple optical method to analyze the Fraunhofer diffraction properties of one-dimensional gratings . With this method we have shown that optical processing can be performed using standard equipment available in most undergraduate physics laboratories. Diffraction   gratings   are   very effective to separate a wave into different wavelengths with high resolution . In fact, the self-similarity of the diffraction patterns can be easily observed and recorded with a CCD camera   to record the power distribution of the Fourier transform in the spatial frequency domain . From figures (4-14) we conclude the peak intensity at each wavelength depends on the number of slits in the grating .

References

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York : Mc Graw-Hill , 1976.
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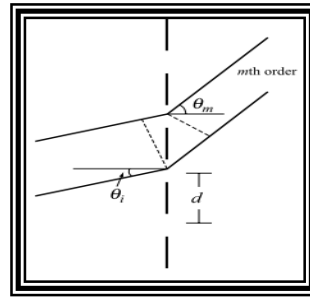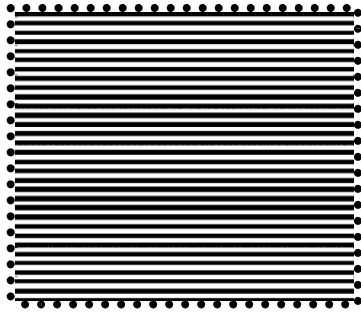[10] Herbert Venghaus ," Wavelength Filters in Fiber Optics" , Springer , 2006 .

Figure 1: Planar view of a transmission amplitude grating [1].

Figure 2 : Periodic amplitude grating[1].
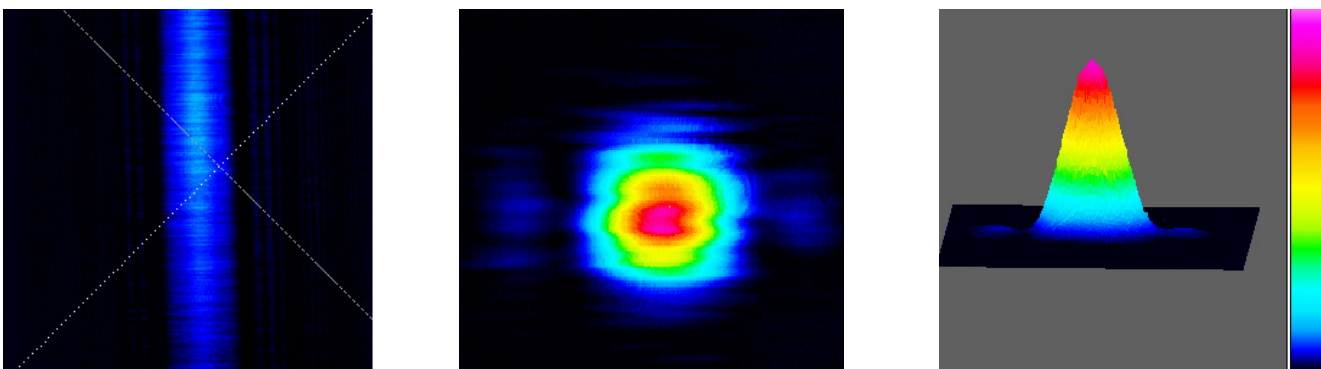

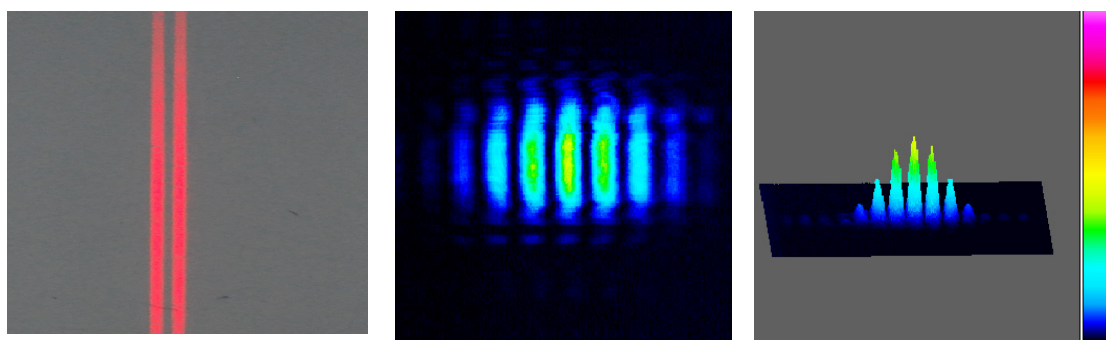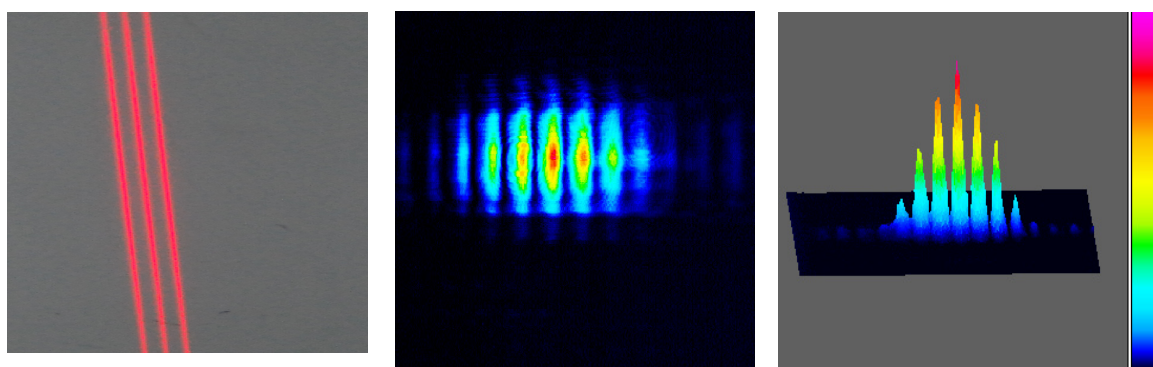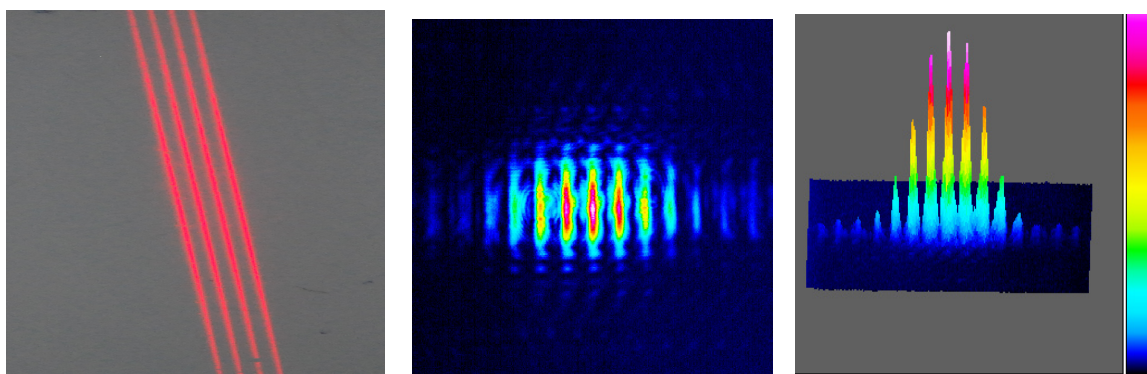*Figure 3: Experimental (2F set-up) system .*

Figure 4: - The single slit recorded in a CCD camera .

Figure 5 : - The double slit recorded in a CCD and digital camera .

Figure 6 : - Three multiple slit recorded in a CCD and digital camera .

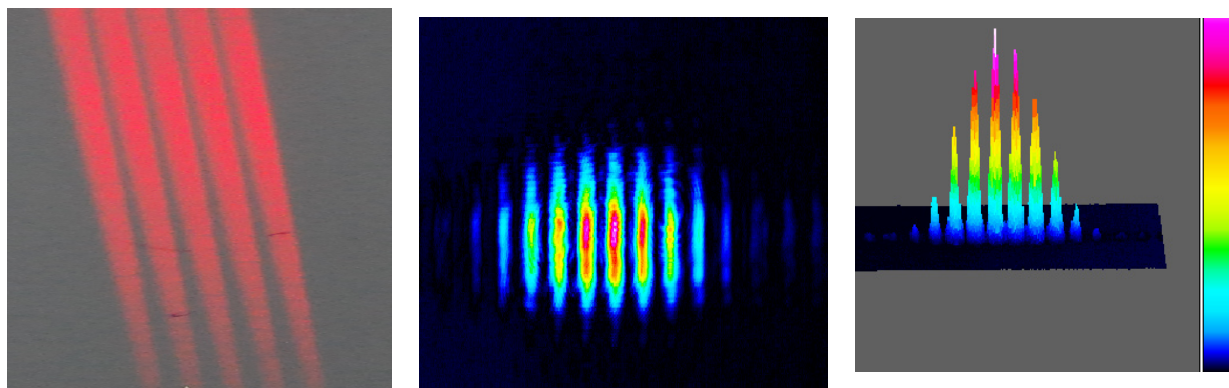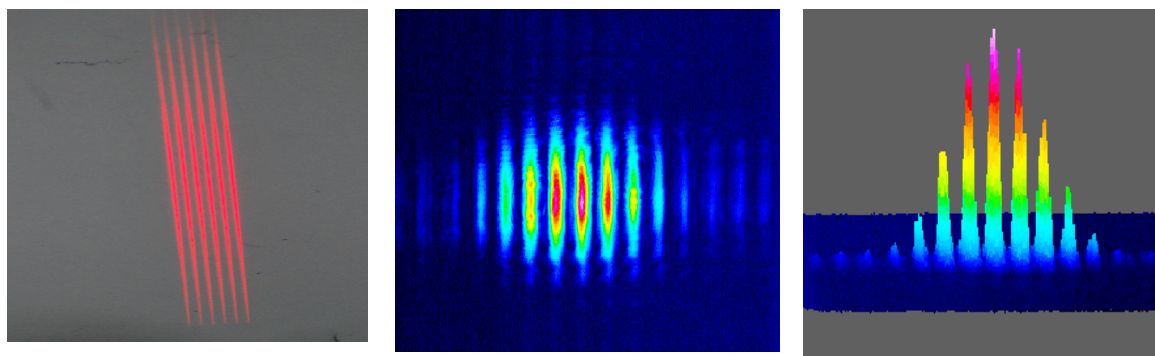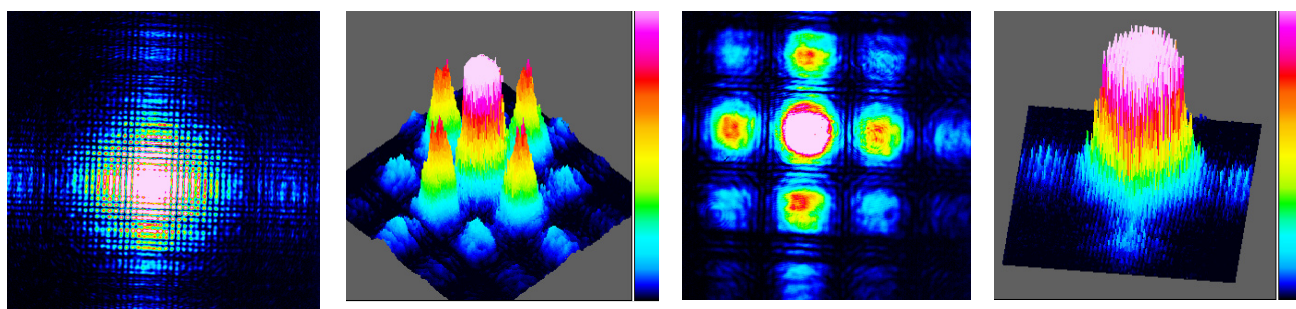*Figure 7: - Four multiple slit recorded in a CCD and digital camera .*

Figure 8: - Five multiple slit recorded in a CCD and digital camera .

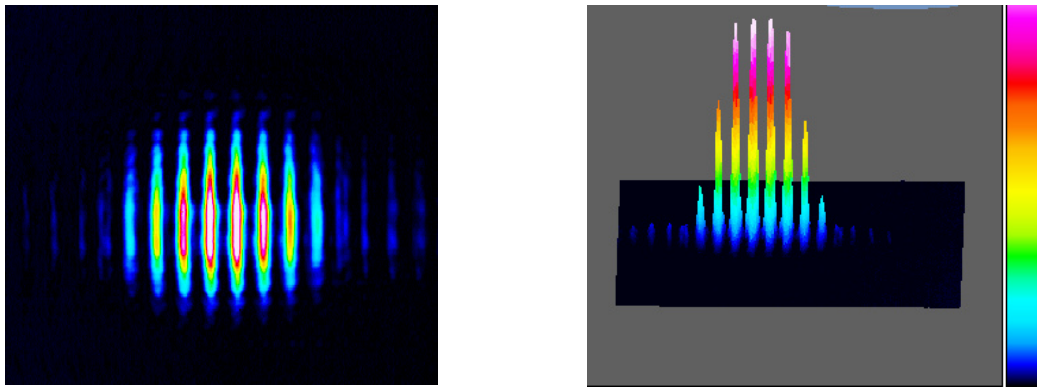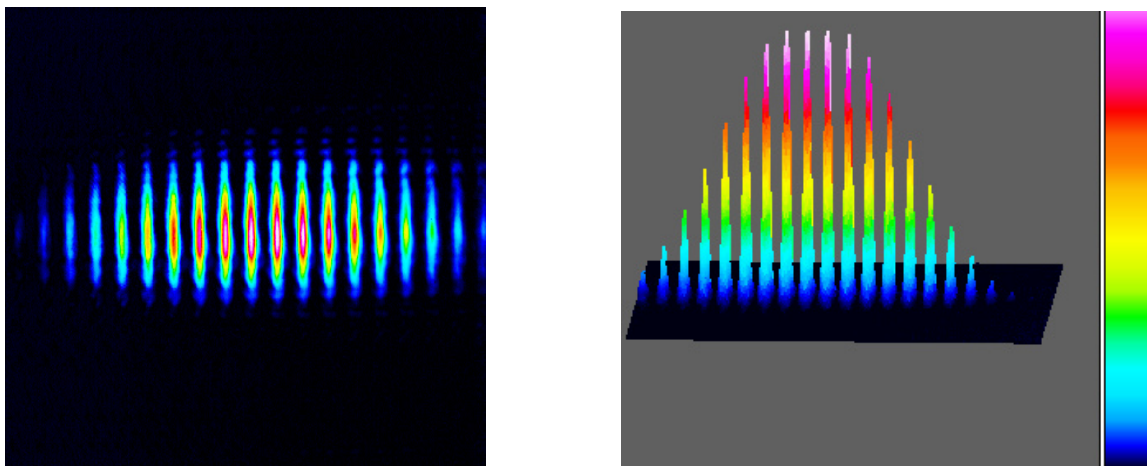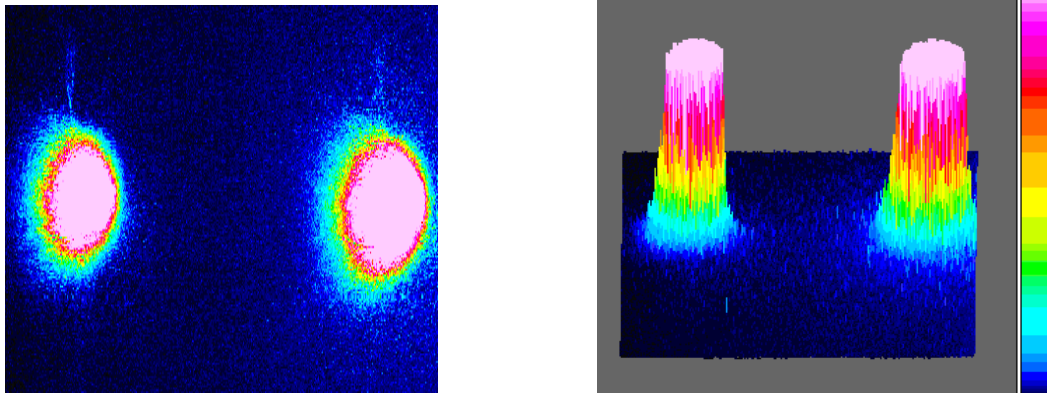*Figure 9: - Six multiple slit recorded in a CCD and digital camera .*

Figure 10 : - Fine Gauze slit recorded in a CCD camera .
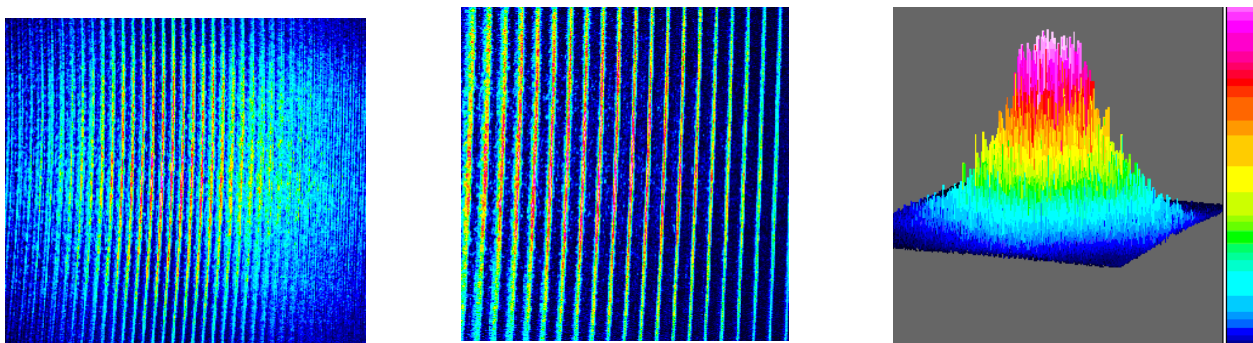
Figure 11: - One Coarse grating slit recorded in a CCD camera .

Figure 12: - Two Coarse grating slit recorded in a CCD camera .

Figure 13 : -   Diffraction grating 50 line/mm recorded in a CCD camera .

Figure 14 : -   Diffraction grating 4 line/mm recorded in a CCD camera .