Fresnel diffraction by abrupt change of amplitude, phase, coherency and polarization

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Abatract:

Conventional Fresnel diffraction occurs as the path of a light beam is partly obstructed by an opaque object. In fact, in this process the amplitude of the beam experiences an abrupt change at the object boundary. Recently it is shown that an abrupt change in the phase of a part of light beam also leads to Fresnel diffraction. In this presentation we show that an abrupt change in the polarization and in the coherency of a part of light beam leads to Fresnel diffraction. We show how these new kinds of diffractions can be exploited for measuring film thickness, refractive index and optical constants of materials and diffusion constant in liquid-liquid diffraction.

Introduction

After A. A. Mickelson introduced his Interferometer in 1881, a lot of attentions focused on application of interference in metrology because Mickelson made it possible to change phase desirably in interference.

Subject of diffraction includes Fresnel diffraction (FD), Fraunhofer diffraction and far–field diffraction. Fraunhofer diffraction has many applications in describing optical systems and in spectrometry, but applications of FD is limited. The limitation is imposed by the nonlinearity of phase in FD and the inability to change the optical path difference (OPD) at will.

Conventional Fresnel diffraction occurs as the path of a light beam partly obstructed by an opaque object. In fact, in this process the amplitude of the beam experiences an abrupt change at the object boundary. Recently it is shown that an abrupt change in the phase of a part of light beam also leads to Fresnel diffraction [1]. Tavassoly and et.al has shown in this kind of diffraction it is possible to change phase at will. This has provided many applications including in the measurement of refractive index, displacement, film thickness and temperature profile around small objects.

Meanwhile it has been shown that Fresnel diffraction can occur as a result of abrupt change in amplitude, phase, polarization and coherency.

Methods of producing FD

1- By abrupt change in amplitude by obstructing a part of wavefront

The conventional FD is produced by putting an opaque obstacle in the way of light beam. You can see the FD from a semi-infinite barrier. (Fig. 1.)

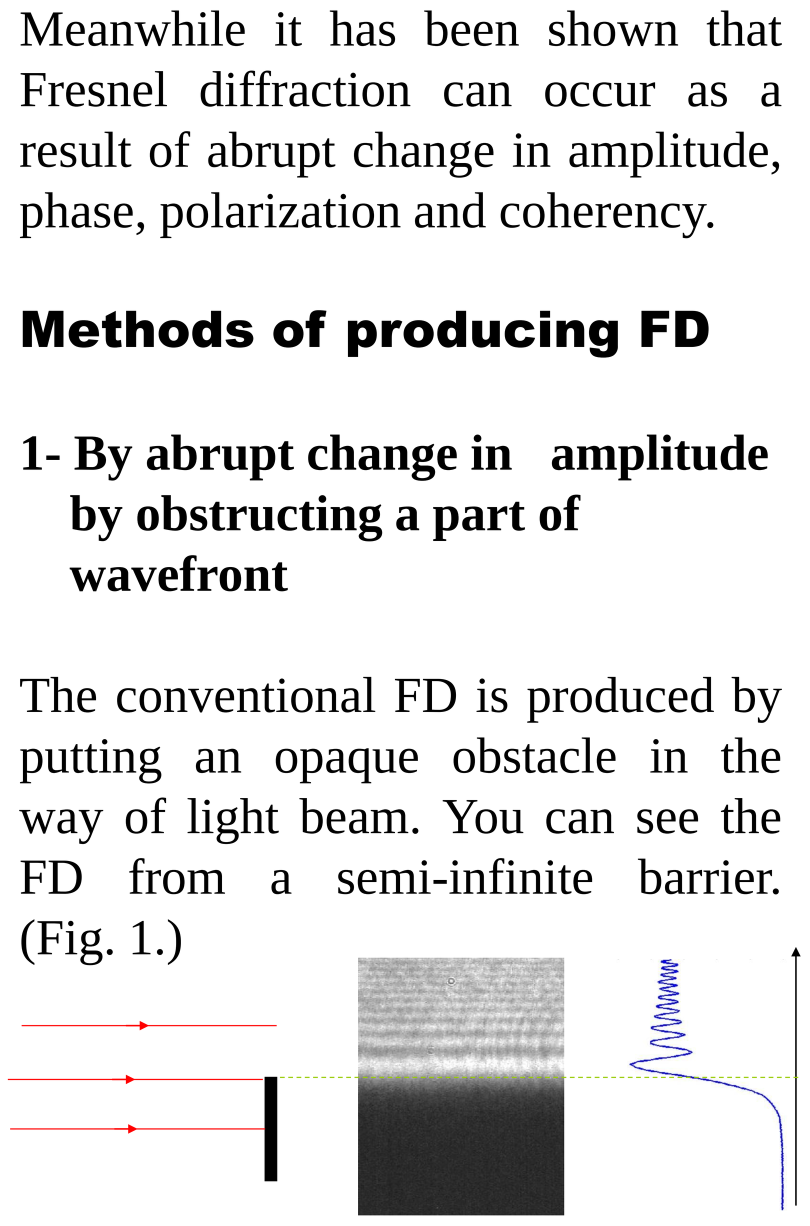

Fig. 1. conventional FD caused by an opaque obstacle.

2-By abrupt change in amplitude by reflecting from the boundary of two different materials.[2]

FD also happens by abrupt change of amplitude but not between zero and 1. This kind of diffraction happens by reflection at the boundary of two materials. (Fig. 2.)

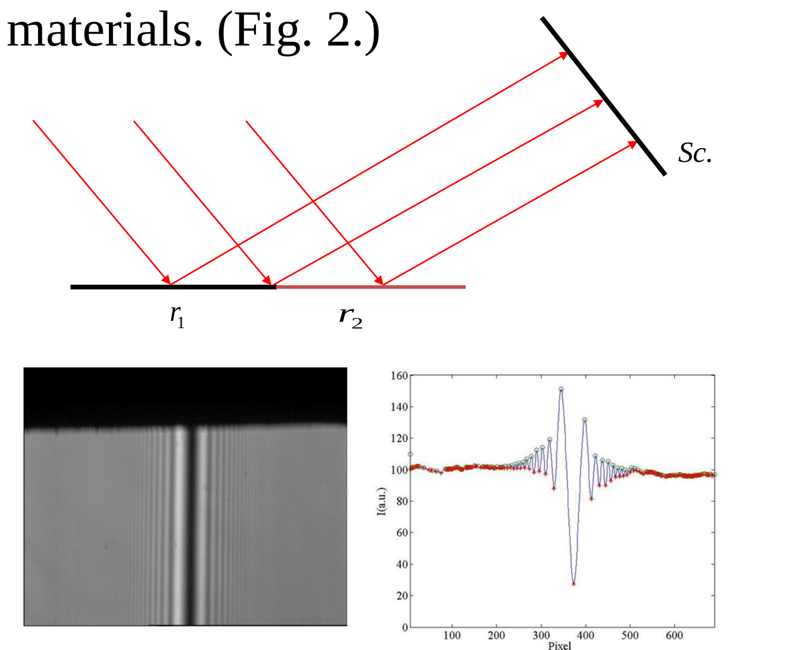

Fig. 2. Diffraction by reflection from the border of Cu and Al thin film.

3- By abrupt change in phase

Also FD occurs when phase of a part of wavefront of light suddenly changes. This happens by reflecting a wave front from a step or passing through a transparent plate immersed in liquid or gas.[1,2,3,4]

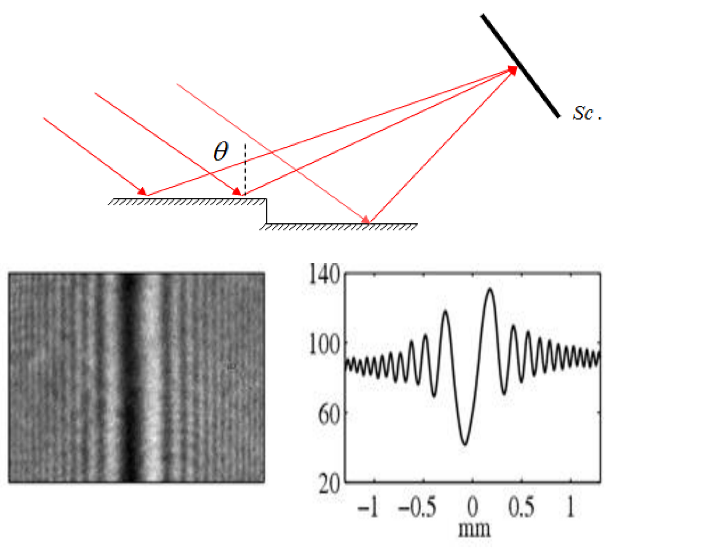

Fig. 3. FD from one dimensional phase step of height λ/8.

4- By abrupt change in coherency of light

It is also seen that FD occurs when a part of a wavefront of light suddenly suffers from a change in coherency. This happens by reflection a coherent beam from the boundary between smooth and rough surfaces.

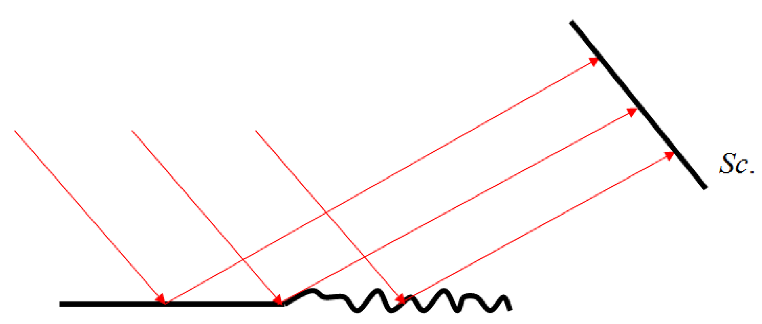

Fig. 4. Beam of light reflected from the boundary of smooth and rough surfaces.

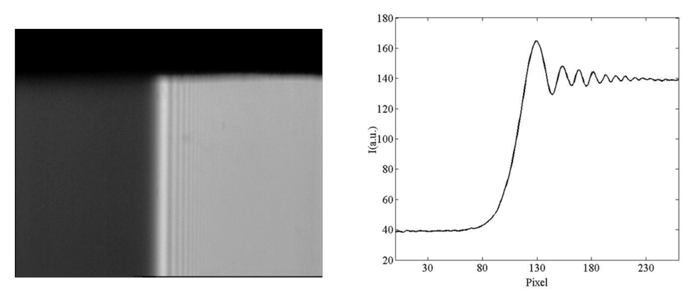

Fig. 5. FD pattern obtained by reflection a beam from the boundary of smooth and rough surfaces.

5- By abrupt change in polarization

Finally it can be shown that FD can occur when a wavefront of light experiences an abrupt change in polarization.

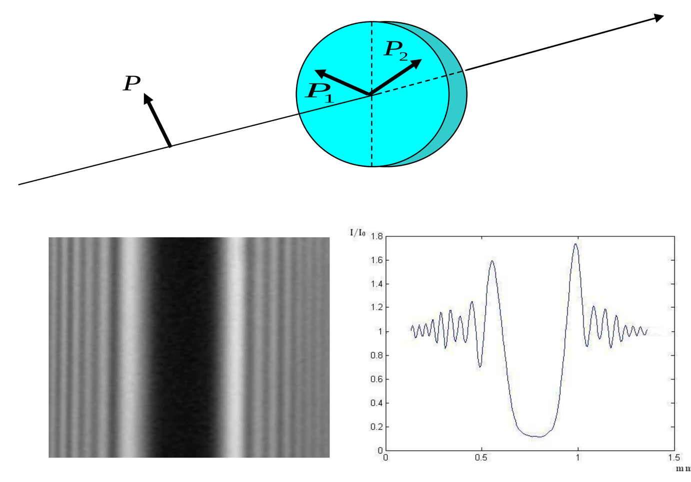

Fig. 6. Diffraction pattern obtained by passing polarized light beam from the boundary of two regions with perpendicular polarization directions.

Some Applications

1- Measurement of film thickness by FD from a phase step

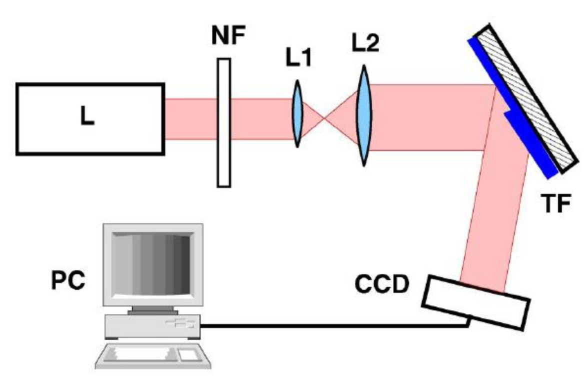

Fig. 7. Experimental setup.

No.	Film Thickness in nm for $\lambda = 532\,\mathrm{nm}$	Film Thickness in nm for $\lambda = 633\,\mathrm{nm}$	Standard Deviation in nm for $\lambda = 532\,\mathrm{nm}$	Standard deviation in nm for $\lambda = 633\,\mathrm{nm}$
1	466	465	6.5	5.9
2	444	446	6.5	5.5
3	239	242	4.8	4.1
4	80	82	3.9	6.1
5	57	55	2.1	2.4
6	39	40	1.5	2

Table 1

Experimental thicknesses obtained for six samples of different thicknesses using two different wavelengths.

2- Optical refractometry based on FD from phase wedge [4]

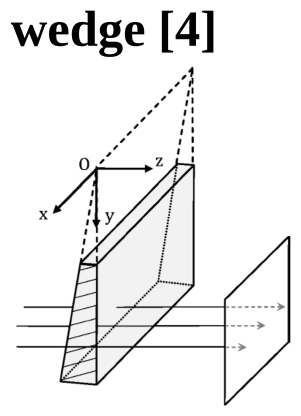

Fig. 8. When a transparent wedge of small apex angle is illuminated by a monochromatic parallel beam of light, diffracted from the two sides of the hatched interface, produces a periodic diffraction pattern. (see Fig. 9.)

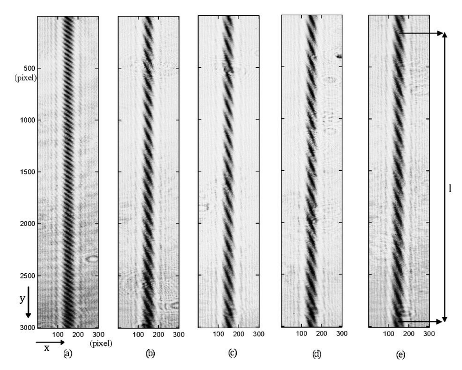

Fig. 9. Diffraction patterns of the expanded He–Ne laser light diffracted from a BK7 wedge of apex angle α ¼ 0:198°, immersed in (a) air, (b) water, (c) acetone, and in ethanol–water solutions of (d) 30% and (e) 80%. The slanted fringes at the center are the traces of the central dark fringe, whose location and intensity vary periodically by the change of the wedge thickness. The arrows represent the directions of the x and y axes in Fig.-8.

Liquid	Refractive Index N
Water	$1.3317 \pm 2 \times 10^{-4}$
Acetone	$1.3578 \pm 2 \times 10^{-4}$
Ethanol	$1.3608 \pm 2 \times 10^{-4}$

Table 2

Refractive Indices of Three Different Liquids

3- Temperature profile around a thin wire carrying electric current [5]

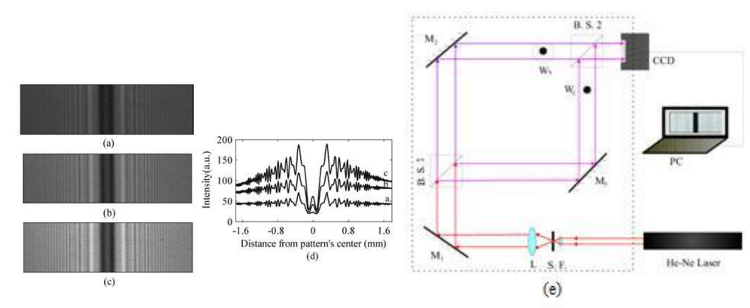

Fig. 10. Diffraction patterns of the light diffracted from a copper wire of thickness 0.4 mm carrying different electric currents after its original diffracted field had been suppressed by the field diffracted from another similar wire installed in the other arm of a MZI. (a) *I=0.12 A. (b) I=0.25 A. (c) I=0.41 A.* (d) The profiles of the intensity distributions of the corresponding diffraction patterns. (e) Diagram of the set up.

Conclusions

This report shows that FD can occur by abrupt change in amplitude, phase, coherency and polarization which can have significant applications. FD by changing coherency provides measurement of coherent and incoherent light that it results in finding roughness of surfaces. FD by changing phase can be applied in measuring the temperature, refraction index, thin films thickness. FD by changing in polarization provides new generation of ellipsometers.

References

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