Significant attenuation of light diffraction by a slit between plates made of the strongly absorbing glass NS12 at the unit relative refraction index

Yu.I. Terent'ev

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

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The attenuation of light diffraction by a slit between plates made of strongly absorbing NS12 glass is achieved when putting the slit into a medium with the same refraction index. The attenuation is characterized by a total disappearance of side diffraction bands, many-fold decrease of the diffraction pattern width, and 3.5-fold increase of its maximal intensity.

Introduction

Experiments on attenuation of light diffraction by a screen at close or equal to unit relative refraction index are described in Ref. 1. In this case, the screen is presented by plates made of strongly absorbing optical glass, placed in a cell with optically homogeneous transparent liquid. Such attenuation turned out especially large in the case of light incidence at $\lambda = 0.53$ μm to a screen plate made of NS12 glass placed in the cell with dimethyl phthalate at a temperature of 21.4 °C. Such temperature corresponds to the same values of refraction index of the plate and liquid and, hence, to the unit relative refraction index $n_{\rm rel}$.

Due to partial transparency of the used glass plates near edges, origination of diffraction bands on an experimental screen within the open part of a light beam can result from the light diffraction by the plate and the interference between the directly passing rays and the refracted ones due to partially transparent plate region. However, the degree of band contrast decreases with the decrease of $n_{\rm rel}$ in conditions when the plates are optically denser media and at $n_{\rm rel} = 1$, which excludes the refraction of incident rays toward the open beam part. Hence, the observed bands have a merely diffraction nature.

After filling the cell with liquid, the absorbing plates continue to overlap the same part of the wave front. Therefore, the diffraction attenuation at $n_{\rm rel} \to 1$ and especially equal to unit in case, when SS8, TS2, TS3, and NS12 glass plates serve as a screen, are beyond the scope of diffraction theories founded on the concept of secondary waves.

Based on the Sommerfeld rigorous solution of the diffraction problem,[2] the diffraction pattern from the screen results from the interference of the non-screened light with the edge light, which is the screen-edge-reflected light.

According to the above solution, the intensity of the originating edge light, and, hence, diffraction pattern contrast degree should differ from those in case of finite conductivity and thickness of actual screens, zero conductivity in dielectrics, and the use of strongly absorbing glass plates as a screen. However, when changing a strongly absorbing IKS3 plate, located in air, by a plate made of Al and Fe, the relative light intensity remains virtually invariable. An essential attenuation of light diffraction has been experimentally ascertained[3] when decreasing the width of Al screen to $5.4 \cdot 10^{-2}$ μm, that witnesses of its complete disappearance in conditions of Sommerfeld problem solution (infinitely thin screen).

The indifference of the obtained Sommerfeld solution to the above-listed factors becomes clear from the experimental results,[4] according to which the screen is not the only source of edge light. Main part of light is originated in the region above the screen (deflection zone), approximately equally deflecting rays from and onto the screen, independently of whether the screen is conductor or dielectric.

The width of this region is clear from the experimentally determined[5,6] equation

$$\varepsilon = 259.5\frac{\lambda}{0.53}/(h_3 + 0.786) = 489.623\lambda/(h_3 + 0.786),$$

where ε defines the edge ray deflection angles, min; h_3 is the distance from the initial ray trajectory to the screen, μm; 0.53 is the green light wavelength, μm.

Since the screen-edge reflected light is not the key reason of the edge light, an essential attenuation of light diffraction at $n_{\rm rel} \to 1$ cannot also be explained by its attenuation at increase of $n_{\rm rel}$.

The above-described effect is considered in this work in case of the plane light wave diffraction at $\lambda = 0.53$ μm and $n_{\rm rel} = 1$ by a slit between NS12 glass plates; the use of which as a screen resulted in the strongest attenuation of diffraction bands.

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The experiments followed the scheme shown in Fig. 1.

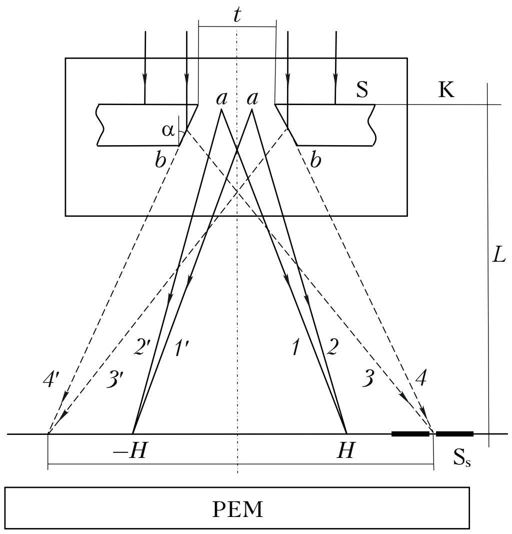

Fig. 1. The scheme of the parallel light beam diffraction by a slit between plates made of strongly absorbing NS12 glass placed in a cell with dimethyl phthalate.

Here K is a cell of 12 mm in width, filled with dimethyl phthalate, where the slit S of plates of 3 mm in thickness with polished faces is mounted in parallel to windows; *1*, *2*, *1'*, *2'* are parallel rays incident onto the slit and deflected within the deflection zones above the plates; *3*, *4*, *3'*, *4'* are the rays passing though partially transparent regions of the plates near the edges *a* and deflected within the deflection zones on both sides of the media interface *ab*; S_s is the scanning slit of 42 μm in width located at the distance L = 109.5 mm from the slit S; t is the width of the slit between plates, equal to 40 μm.

If a thin screen (blade) is replaced by a thick one with a flat face parallel to the axis of light beam, the intensity of edge rays propagating from the screen increases approximately four-fold. This is caused by the incidence of some rays (*2*), deflected toward the shadow in the deflection zone, onto a considered face. After reflection from the face, they are imposed upon oppositely deflected edge rays (*1*).[7] Due to half-wave loss in reflection, rays *1* and *2*, having the non-geometric path-length difference $\Delta_{ng} = 0.5\lambda$ at the starting moment after their deflection,[8–10] interfere without path-length difference and, hence, mutually intensify each other.

In contrast to the edge ray intensification on the illuminated face, the light intensity significantly decreases within the shadow due to 0.5λ-shift superposition of edge rays propagating in the screen shadow after reflecting from the face upon edge rays *2* deflected directly in the shadow.

When the thick screen is turned through 11° angles relative to the front edge of the considered face away from the beam axis, the beams deflected to this face, gradually cease to reach the face and to reflect from it. Hence, the thick screen becomes equivalent to a thin one.

In accordance with the above-considered facts, to study the light diffraction by a slit between thin screens, *ab* edges of the plates have the angle α = 12° with the beam axis.

The NS12 glass refraction index $n_з$ = 1.5207 and the index of absorption $K_\lambda = \log\tau_\lambda = 3.4$ [Ref. 11] (τ_λ is the attenuation factor of glass of 1 mm in thickness).

NS12 plates are virtually opaque inside. Being placed in the dimethyl phthalate, they are partially transparent near the edges *a* due to the above α value and 7.1-fold attenuate the incident light at a distance of 55 μm from *a* at $n_{rel} = 1$.

In the absence of dimethyl phthalate in the cell, the light incident on the plates near edges *a* undergoes a total internal reflection from *ab* faces. As a result, the diffraction pattern from the slit is formed by the rays incident directly on the slit. Similarly to the standard pattern, there are side bands in addition to the central maximum ($\max_0$) of 2.9 mm in width in the above diffraction pattern. The intensity ratio $\max_0/\max_1$ equals to 20.8 ≈ ≈ 1/0.047.[12] Curve *1* in Fig. 2 characterizes the light intensity distribution over the width of the given pattern in the scanning plane (I is the light intensity).

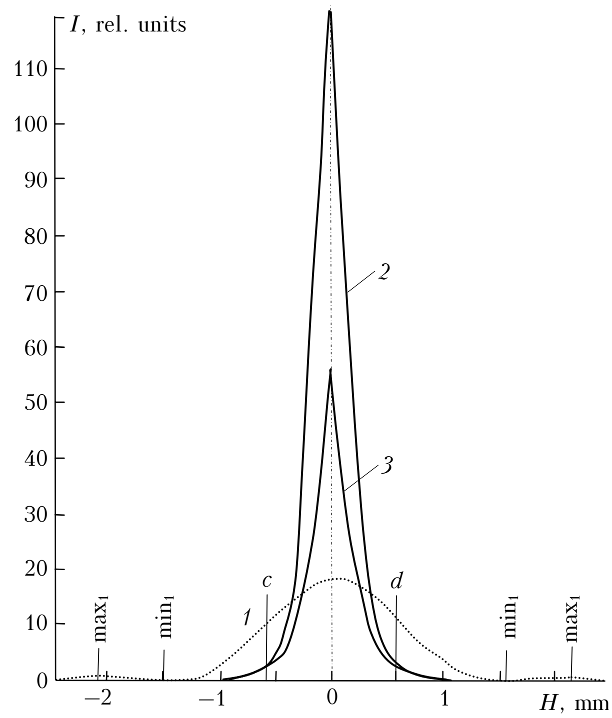

Fig. 2. Diffraction patterns of a slit between plates made of HC12 glass in air and in dimethyl phthalate (open and closed, $n_{rel} = 1$).

After filling the cell with dimethyl phthalate at the temperature t_c = 21.4 °C ($n_{rel} = 1$), side bands completely disappear and the central maximum narrows to 1.8 mm with simultaneous 6.534-fold increase of the intensity (Fig. 2, curve *2*) at the same incident light beam.

This maximum is resulted from the combined effect of rays, passing through the slit, and a plate near their edges *a*. In case of a closed slit ($t = 0$), the maximum is formed only by rays passing through the plates; as a result, the intensity decreases down to the values characterized by curve *3*, while the width does not change.

When rising the temperature up to 29 °C and, hence, decreasing the dimethyl phthalate refraction index due to the appearing ray reflection on *ab* faces, the reflected beams shift away from the slit axis till their almost total splitting, characterized by curve *4* in Fig. 3.

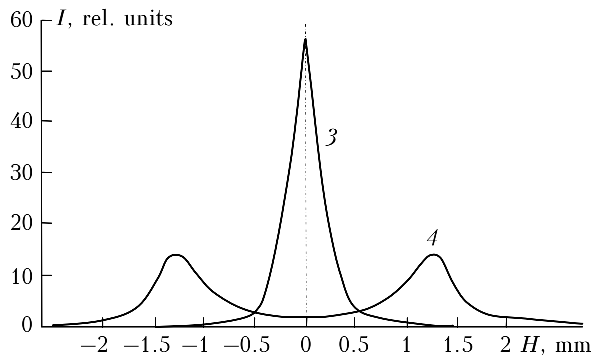

Fig. 3. Diffraction patterns from a closed slit at $t_c = 21.4$ (*3*) and 29 °C (*4*).

As is seen from the comparison of curves *3* (taken from Fig. 2) and *4*, the reflected beams are of similar width, equal to the width of maximum corresponding to curve *3*, and the same I, four-times less then the maximum I on curve *3*. Hence, the beams, outgoing from the plates, interfere on the slit axis without path-length difference.

The difference $(S_2 - S_3)$ of areas, limited by curves *2*, *3*, and the axis H in the range c–d (see Fig. 2), is equal to the area S_1, limited by the axis H and curve *1*, i.e., the light beam, passing through the slit after its dipping into dimethyl phthalate, keeps its previous value and narrows to the width cd, which is equal to 1.25 mm, that is much less than the width of the diffraction pattern from the slit in air. This is the evidence of a decrease in beam deflection efficiency in the deflection zone at $n_{\text{rel}} \to 1$ and especially at $n_{\text{rel}} = 1$.

In the range c–d, $(S_2 - S_3)/S_3 = 1.181$ and $(I_{2\max} - I_{3\max})/I_{3\max} = (118 - 55) = 1.145$, which is close to 1.181. It is possible to conclude from this, that $(I_{2\max} - I_{3\max})$ approximately equals to the maximum intensity $I_{4\max}$ of light, passing through the slit in dimethyl phthalate.

The equality of $I_{2\max}$ to the sum of maximum intensities of rays, arriving from the plate and through the slit to the beam axis, following from the above, points out to the existing path-length difference $\Delta \approx 0.5\lambda/2$ between them.

Because of beam narrowing, $I_{4\max}$ is $63/18.06 = 3.49$ times larger than the analogous I in case of slit in air.

After placing the slit in dimethyl phthalate, the angular half-width of the outgoing beam is

$$\gamma = \frac{cd}{2L} \cdot 57.3° \cdot 60' = \frac{1.25 \cdot 3438'}{2 \cdot 109.5} = 19.6'.$$

There are no edge rays beyond the slit. The angle γ is larger than $\varepsilon = 15.9'$ – the angle of deflection of edge rays, arriving to the maximum of the diffraction pattern from a NS12 plate in Ref. 1. Therefore, $\max_1$ is still observed there.

In case of incidence on the screen of the divergent beam, the magnitude of ε of edge rays arriving to $\max_1$ at invariable L increases with decreasing l, the distance between a linear light source to the screen, equal in Ref. 1 to 14 mm due to the increasing distance between $\max_1$ and the shadow boundary.[9] The decrease of l to the values corresponding to $\varepsilon \to \gamma$ should evidently result in total disappearance of bands in the diffraction pattern.[1]

When changing the divergent light beam incident on a NS12 plate by a parallel beam ($l = \infty$), while conserving the previous distance between the plate and the plane of diffraction pattern scanning, the deflection angle of edge rays, arriving to $\max_1$, decreases from 15.9′ to 5.35′. Due to the increase in edge ray intensity with decreasing ε [Ref. 8], this results in the increase in relative light intensity from 1.72 to 1.224 in $\max_1$; from 1.039 to 1.177 in $\max_2$; and in the decrease from 0.997 to 0.796 in $\min_1$. However, despite the increase in the degree of contrast of the diffraction bands, they were absent as before at angles $\varepsilon > \gamma$.

The light beam, going out near the edges *a*, widens by 1.8–1.25 mm more than beams, passing through the slit. This is the evidence of the presence of deflection zones on both sides of the media interface and the beam deflection there in one direction.

When a screen or slit-forming screens are in the liquid medium, the deflection of light rays in the considered experiments takes place in the resulting zone, consisting of overlapping zones of oppositely located screen and the adjoint medium, and, hence, affecting the rays in opposite directions. This reduces their deflections, which increase with a decrease in differences in optical densities of adjoint media, i.e., at $n_{\text{rel}} \to 1$.

The considered diffraction attenuation of light, passing through the slit at $n_{\text{rel}} = 1$, manifesting itself in complete disappearance of side bands and multiple decrease of the light beam angular width, is beyond the scopes of the existing theories of light diffraction and, hence, along with Refs. 13–20 is of interest for deeper understanding of the phenomenon reasons and light nature, as well as for practical purposes.

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