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Analysis and elimination of boundary reflections in transmission holograms

A. Beléndez (†)*, **C. Neipp** (†) **and I. Pascual** (‡)

(†) *Departamento de Física, Ingeniería de Sistemas y Teoría de la Señal.*
Universidad de Alicante. Apartado 99, E-03080 Alicante (SPAIN)

(‡) *Departamento Interuniversitario de Óptica.*
Universidad de Alicante. Apartado 99, E-03080 Alicante (SPAIN)

Phone: +34-96-590 36 51
Fax: + 34-96-590 34 64
E-mail: augusto@disc.ua.es

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*corresponding author

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ABSTRACT

Elimination of reflections which occur at the glass-air interface of holographic plates is an important factor to be taken into account when recording transmission holograms. If these reflections are not eliminated, unwanted secondary gratings are stored due to interference of the object and reference beams with the beams reflected at the interface. This not only gives rise to an anti-aesthetic effect but also produces a reduction in diffraction efficiency and an increase in noise. We present the results obtained using a method which eliminates these unwanted reflections. This method, instead of using liquids, makes use of a black self-adhesive PVC masking tape stuck on the glass side of the holographic plate. We carried out a qualitative analysis of the different results obtained for plates with and without black PVC tape and also quantitatively analyzed the effect of the tape on the reflectivity of the plates as well as the density of holographic gratings. The results obtained confirm the applicability of the method described for antihalation reduction and elimination of unwanted reflections that cause interference affecting the quality of the holographic image.

KEYWORDS: Rear reflections, optical density, holography

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1. Introduction

The photographic plates normally used in holography consist of an emulsion deposited on a glass substrate. When a hologram is recorded on this type of plate, the beams of light undergo reflections at the various interfaces: air-emulsion, emulsion-glass and glass-air (Fresnel's reflections). The intensity of this back-reflected radiation may be sufficient to produce significant interference with the direct object and reference beams being used to record the hologram. This results in an unwanted interference pattern causing smear and halos in the holographic image. This spurious interference pattern is not only anti-aesthetic but also produces a reduction in the diffraction efficiency and an increase in noise [1]. Bearing in mind that the normal refractive index of a photographic emulsion is 1.64 and that of the glass substrate is 1.51 (values measured for Agfa 8E75 HD holographic plates [2]), it can be seen that the most significant amount of back-reflected light occurs at the glass-air interface at the back of the holographic plate. For example, with these values and using light polarized perpendicular to the plane of incidence inciding at an angle of 30° (in air), reflectance at the emulsion-glass interface is 0.15%, while reflectivity at the glass-air interface is 6%. This implies that it is possible to create interference fringes with a visibility V of 0.46, where V is defined by the equation:

$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2} \qquad (1)$$

Some methods exist to reduce or eliminate the back-reflection effect [3], the Brewster-angle method, for example. However, the methods commonly used are the following: matching the refractive index difference at the glass-air interface and absorbing the transmitted radiation or using an antireflection coating at the interface. There are several index matching liquids [3-6] (see Table 6.1 of reference 3), but since the refractive indexes of the emulsion and of the glass substrate differ, it is not possible to obtain perfect index matching. Most of these liquids are toxic [3], such as xylene, kerosene, orthoxylene or toluene. Also, the use of index-matching methods is usually complex in terms of practical application [7] and the results obtained are not completely satisfactory.

A simple, alternative procedure to efficiently eliminate the back-reflected light produced at the glass-air interface at the rear side of the plate was proposed by Soares in a

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brief note [8]. The method consists in sticking a black self-adhesive PVC masking tape onto the back surface of the plane parallel glass plate. The refractive indexes are matched by the glue on the adhesive tape, and the radiation is absorbed by this black tape so that the effects of the spurious interference are considerably reduced. However, Soares' brief paper did not include a quantitative study of this proposed method.

In this paper we analyse the technique proposed by Soares both qualitatively and quantitatively. To do this, we will analyze the reflectivity as a function of the angle of incidence for photographic plates masked with black self-adhesive PVC tape and the findings will be compared with those obtained for the same plates without adhesive tape. Obviously, in the case of photographic plates it is not possible to eliminate the reflection that occurs at the emulsion-glass interface, but, as will be seen, the intensity of the reflected light at this surface is very small due to the small difference between the refractive index of the emulsion and that of the glass. Also, the results obtained for photographic plates will be compared with those corresponding to the glass substrate of the same plates from which the emulsion has been removed. Finally, transmission holographic gratings will be recorded using plates with and without black self-adhesive PVC tape and the aspect of these gratings studied as well as the values of density and diffraction efficiency.

2. Analysis of the reflectivity

Figure 1 shows the schematic optical arrangement of the experimental setup used to verify the applicability of the method described. We used an Agfa 8E75 HD holographic plate measuring 2.5" x 2.5" consisting of a glass substrate with a thickness of 1.53 ± 0.01 mm and a ~6 μm thick layer of emulsion. Black self-adhesive PVC masking tape was stuck onto the glass side of the photographic plate covering half of it. The emulsion side of the plate was illuminated with a collimated beam of light from an He-Ne laser inciding at an angle to the normal in such a way that half the beam incided on the part of the plate masked with PVC tape, while the other half of the beam did so on the unmasked part of the plate. A photographic film was then placed perpendicular to the reflected beam and a photograph was taken. The experiment was repeated using the glass substrate of the holographic plate. The emulsion was completely removed and the glass plate was immersed in a chromic mixture solution for 24 hours. The plate was then rinsed in running water and dried.

Figure 2 shows a photograph taken in the beam reflected by the holographic plate

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(with emulsion) and in the beam reflected by the glass substrate of the holographic plate (without emulsion). As can be seen, in both cases fringes corresponding to interference between the rays reflected by the first side of the plate and those reflected by the second appear in the region not covered by the black PVC tape. However, in the region corresponding to the part of the plate masked with adhesive PVC tape, the reflected beam has a uniform appearance without interference fringes. This indicates that there is hardly any light reflected by the second side of the glass plate.

In order to carry out a quantitative analysis of the results obtained using self-adhesive PVC masking tape as a means of eliminating the light reflected at the glass-air interface of holographic plates, the reflectivity R was analyzed as a function of the angle of incidence θ. This was done for the holographic plate (with emulsion) and for the glass substrate of the same plate (without emulsion). The reflectivity for plates with and without black self-adhesive PVC masking tape was also measured. As in the previous experiment, an Agfa 8E75 HD holographic plate was used. The plate was mounted on a motorized rotation stage which was controlled electronically using a DC point-to-point motion controller connected to a personal computer across an IEEE-488 interface. The rotating device had a resolution of 0.001° and the plate was illuminated using a collimated beam from an He-Ne lasar polarized perpendicular to the plane of incidence. The incident, I_i and reflected, I_r light intensities were measured by means of an optical power meter. The reflectivity R was calculated as the quotient I_r/I_i varying the angle of incidence between 10° and 30° with intervals of 0.5°. In a second experiment, the reflectivity R was measured varying the angle of incidence between 20.0° and 20.3°. Figure 3 shows the results for the reflectivity as a function of the angle of incidence corresponding to the holographic plate, while Figure 4 shows the results obtained with the glass plate. As can be seen in both these figures, when self-adhesive PVC masking tape is not used, the reflectivity oscillates, depending on the angle of incidence, with a high frequency of oscillation (Figures 3(b) and 4(b)) since the thickness of the glass plate is considerable. In the case of the holographic plate, the reflectivity measured corresponds to interference of the beams reflected at the air-emulsion, emulsion-glass and glass-air interfaces, while in that of the glass plate the reflectivity corresponds to interference of the light reflected at the two sides of the plate.

However, when the results corresponding to both the holographic plate and the glass

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plate with adhesive PVC tape are analyzed, it can be seen that the high frequency oscillation practically disappears and, in the case of the holographic plate, the reflectivity oscillates at a much lower frequency. This low frequency oscillation is due to the fact that the reflectivity is a result of the light reflected by the air-emulsion and emulsion-glass interfaces, and its frequency is low because the layer of emulsion is very thin. Figure 5 shows the reflection of the beam of light by the holographic plate and by the glass plate when the glass surface is masked with black PVC tape and it is assumed that the light reflected by the glass-air interface is negligible. In the case of a holographic plate, the reflectivity R of a holographic emulsion (labelled e) sandwiched between air (labelled a) and a glass substrate (labelled g) is expressed as [7]:

$$R = r_{ae}^2 + (t_{ae}r_{eg}t_{ea})^2 \exp(-\alpha s) + 2r_{ae}t_{ae}r_{eg}t_{ea} \exp(-\alpha s/2) \cos\left(\frac{2\pi}{\lambda} n_e d \cos\theta'\right) \tag{2}$$

In this equation r_{ik} and t_{ik} are the Fresnel amplitude reflection and transmission coefficients of a plane wave traversing the interface between the media i and k going from i to k. The refractive index of the photographic emulsion is n_e, α is the absorption coefficient of the emulsion, d is the emulsion thickness, λ is the wavelength in air, $s = d/\cos\theta'$, and θ' is the angle of the incident beam inside the emulsion. It is the cosine term in equation (2) that produces a low frequency oscillation in the reflectivity R. If we now consider the glass plate masked with PVC tape and if we assume that only reflection at the glass-air interface at the first side of the plate is present, the reflectivity R will be given by the equation:

$$R = r_{ag}^2 \tag{3}$$

where r_{ag} is the Fresnal amplitude reflection coefficient for the air-glass surface. As can be seen in equation (3), there is no oscillation term, as occurs in Figure 4(a), where it can be seen that the experimental results for the reflectivity do not oscillate when black PVC masking tape is used. This study of the reflectivity demonstrates that the procedure for elimination of reflections which occur at the glass-air interface of holographic plates gives rise to optimum results and can therefore be applied to the case of transmission holograms.

3. Effect on transmission holographic gratings

Experiments were carried out with Agfa 8E75 HD plates. Unslanted holographic transmission diffraction gratings were recorded on each plate by using two collimated beams from a 15 mW He-Ne laser (633 nm) making an angle of 45° (in air) with each other. With the geometry described the spatial frequency of the gratings was calculated as 1200 lines/nm. The total intensity was 500 μW/cm^2 and the beam intensity ratio was 1:1. Eight holographic gratings were recorded for different values of exposure (four on each plate), and four plates were used, only two of which were masked with adhesive PVC tape. After exposure and before processing the masking tape was peeled off from the glass surface. The exposed plates were processed according to the processing schedule shown in Table I and amplitude holograms were obtained.

Figure 6 shows a photograph of the results obtained. Plates (a) and (b) were recorded masked with black PVC tape, while plates (c) and (d) were recorded without the tape. The values of exposures for gratings of plates (a) and (b) were the same than for the gratings of plates (c) and (d). If we compare plates (a) and (c), it can be seen that no interference fringes are observed on the former while on the latter these fringes are clearly seen (the lighter grating on plate (c)). Also, on plate (d) there is a halo which does not appear on plate (b). This halo may be due to the light diffused by the silver halide grains of the emulsion. This light, after being reflected at the glass-air interface, reaches areas of the plate outside the illuminated circle.

The density D of each of the gratings was then measured and represented as a function of the exposure. Figure 7 shows the results obtained for the plates with and without black self-adhesive PVC masking tape. The fog density of the plates measured in the regions not affected by the light was D = 0.2. As can be seen in Figure 7, the density is higher for plates without PVC tape, especially at high exposures. This is due to the fact that the light incident on the emulsion comes not only from the object and reference beams, but also from the beams reflected at the glass-air interface. We also measured the density corresponding to the halo surrounding the grating of maximum exposure (E = 500 μJ/cm^2) which is the one to the right of plate (d) in Figure 6 (plate without PVC tape), and obtained a value of D = 2.3. For the same grating but in the case of plate (b) with black PVC tape, the density measured at the same point around the grating was D = 0.2, which

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was the same as the fog density. It can be seen in Figure 7 that a density of D = 2.3 corresponds to an exposure of 15 μJ/cm^2, which is the exposure at which light reaches the non-illuminated area around the grating. As we have already pointed out, this is due to scattering of light by the silver halide grains. This radiation, after being reflected at the glass-air interface, reaches areas of the plate which are not directly illuminated.

4. Conclusions

We have analyzed a simple method which enables unwanted reflections occuring at the glass-air interface of holographic plates during recording of holograms to be eliminated. The method consists in sticking a black self-adhesive PVC masking tape onto the back of the holographic plate and has the advantage that its practical application is straightforward compared to other methods involving the use of matching liquids which are often dangerous or toxic. We analyzed the reflectivity for holographic plates with and without black self-adhesive PVC masking tape and confirmed that the results obtained when adhesive tape is used, for both holographic plates and glass plates, are those that would be expected if no light is reflected at the glass-air interface. The applicability of the method analyzed has been verified by studying the transmission holographic gratings. We have shown that with this method it is possible to eliminate not only unwanted secondary diffraction gratings due to interference of the object and reference beams with the beams reflected at the glass-air interface, but also the halos due to scattering of the incident light by the silver halide grains which is also reflected at the glass-air interface. The density of the plates was analyzed, confirming that better results are obtained using plates with black PVC masking tape.

Acknowledgments

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REFERENCES

1.- **Phillips, N. J., Gwynn, P. G. and Ward, A. A.** Modulation mechanism in the holographic display, Proc. SPIE **212**, 10-16 (1980).

2.- **Kostuk, R. K. and Goodman, J. W.** Refractive index modulation mechanism in bleached silver halide holograms, Appl. Opt. **30**, 369-371 (1991).

3.- **Bjelkhagen, H. I.** *Silver-Halide Recording Materials* (Springer-Verlag, Berlin, 1995), pp. 53-55 and pp. 238-241.

4.- **Richter, A. K. and Carlson, F. P.** Holographically generated lens, Appl. Opt. **13**, 2924-2930 (1974).

5.- **Chang, C. T. and Bjorkstam, J. L.** Amplitude hologram efficiencies with arbitrary modulation depth, based upon a realistic photographic film model, J. Opt. Soc. Am. **67**, 1160-1164 (1977).

6.- **Quintanilla, M., Frutos, A. M. and Arias, I.** Characterization of volume and phase holographic gratings, Appl. Opt. **23**, 214-217 (1984).

7.- **Tholl, H. D., Döhmen, M. and Stojanoff, C. D.** Determination of the mean refractive index and the thickness of dichromated gelatin holographic films using the thin film resonance method, Proc. SPIE **2405**, 76-87 (1995).

8.- **Soares, O. D. D.** Elimination of rear reflections in holographic plates, Am. J. Phys. **48**, 409-410 (1980).

BELÉNDEZ, Augusto; NEIPP, Cristian; PASCUAL, Inmaculada. "Analysis and elimination of boundary reflections in transmission holograms". Optics & Laser Technology. Vol. 30, Issue 8 (Nov. 1998). ISSN 0030-3992, pp. 555-560 DOI: 10.1016/S0030-3992(99)00014-6

FIGURE CAPTIONS

Fig. 1: Diagram of the optical arrangement of the experimental set up used to eliminate reflections at the glass-air interface of holographic plates

Fig. 2: Photograph of the reflected beam using the setup in Figure 1 for: (a) an Agfa 8E75 HD plate and (b) the glass substrate of an Agfa 8E75 HD plate.

Fig. 3: Reflectivity as a function of the angle of incidence for an Agfa 8E75 HD holographic plate with and without black PVC masking tape. (a) Interval between 10° and 30°. (b) Interval between 20.0° and 20.3°.

Fig. 4: Reflectivity as a function of the angle of incidence for the glass substrate of an Agfa 8E75 HD holographic plate with and without black PVC masking tape. (a) Interval between 10° and 30°. (b) Interval between 20.0° and 20.3°.

Fig. 5: (a) Reflection of a laser beam off the photographic emulsion with black PVC masking tape. (b) Reflection of a laser beam off the glass substrate with black PVC masking tape.

Fig. 6: Photograph of amplitude holographic diffraction gratings obtained with black PVC masking tape, (a) and (b), and without black PVC masking tape, (c) and (d).

Fig. 7: Density as a function of the exposure of amplitude holographic diffraction gratings obtained with and without black PVC masking tape.

TABLE CAPTIONS

Table I: Processing schedule.

TABLE I

1. Develop in D-19 for 5 min.

2. Rinse in running water for 2 min.

3. Soak in nontanning fixer F-24 for 3 min.

6. Wash in running water for 10 min.

8. Dry in dissecator for 24 h at 20° C and RH < 20%.

All solutions are at 20°C.

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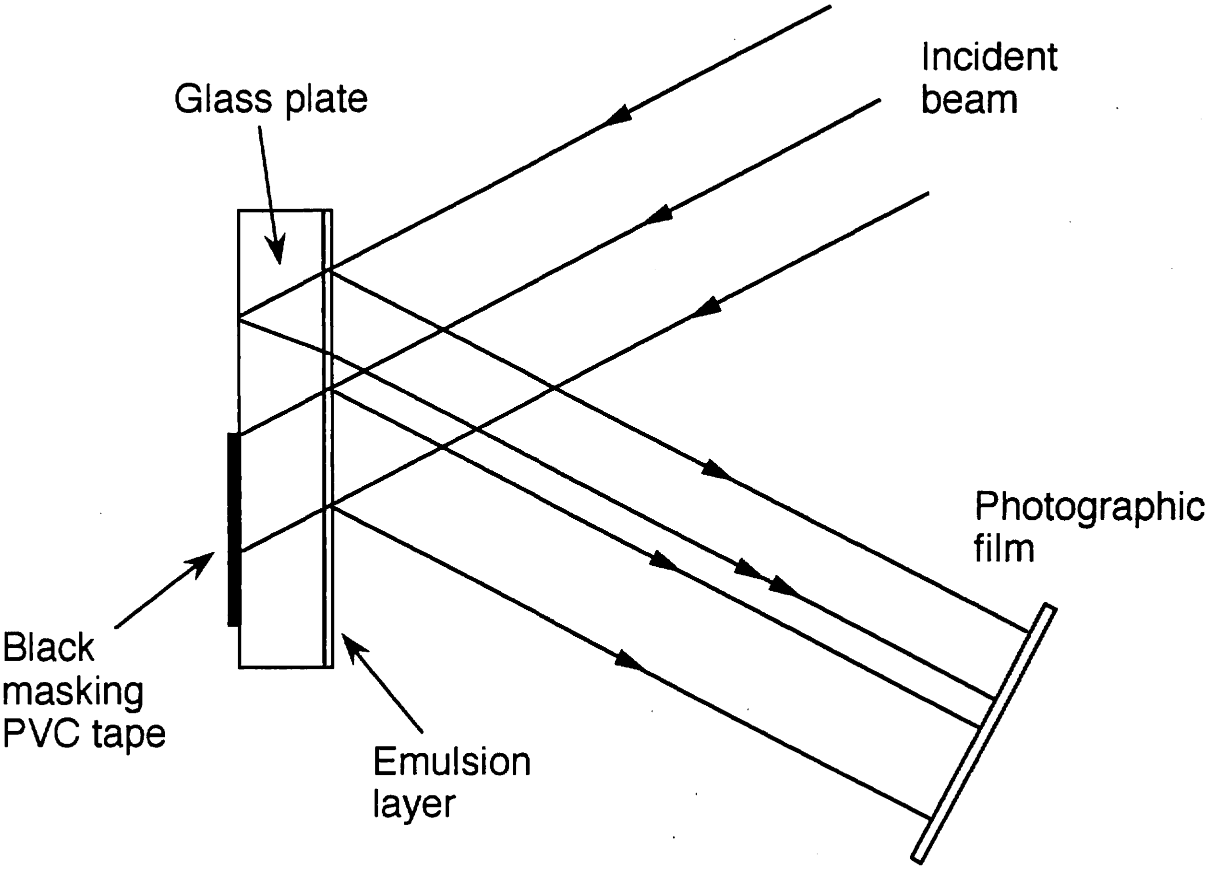

FIGURE 1
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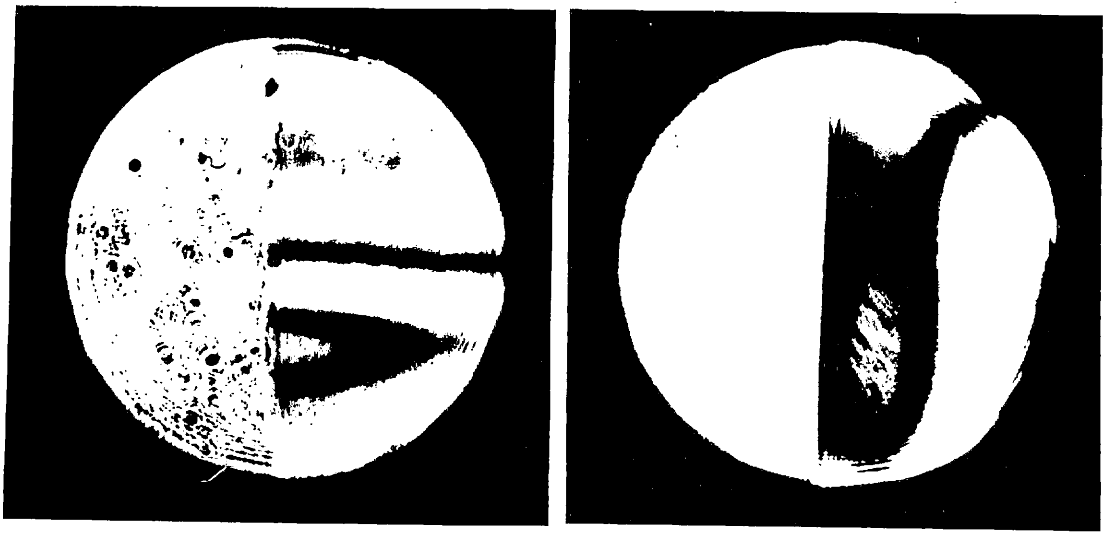

(a) (b)

FIGURE 2
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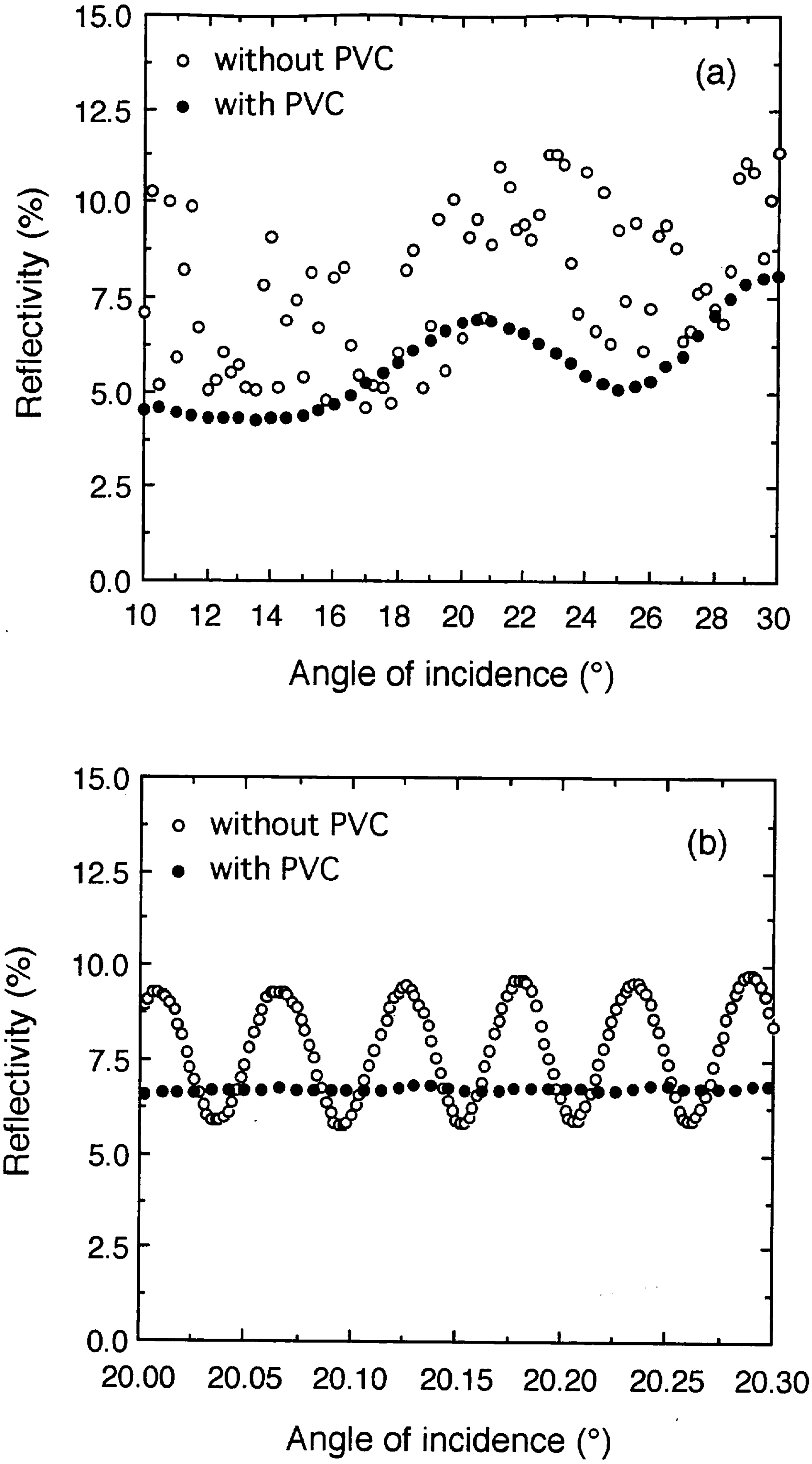

FIGURE 3
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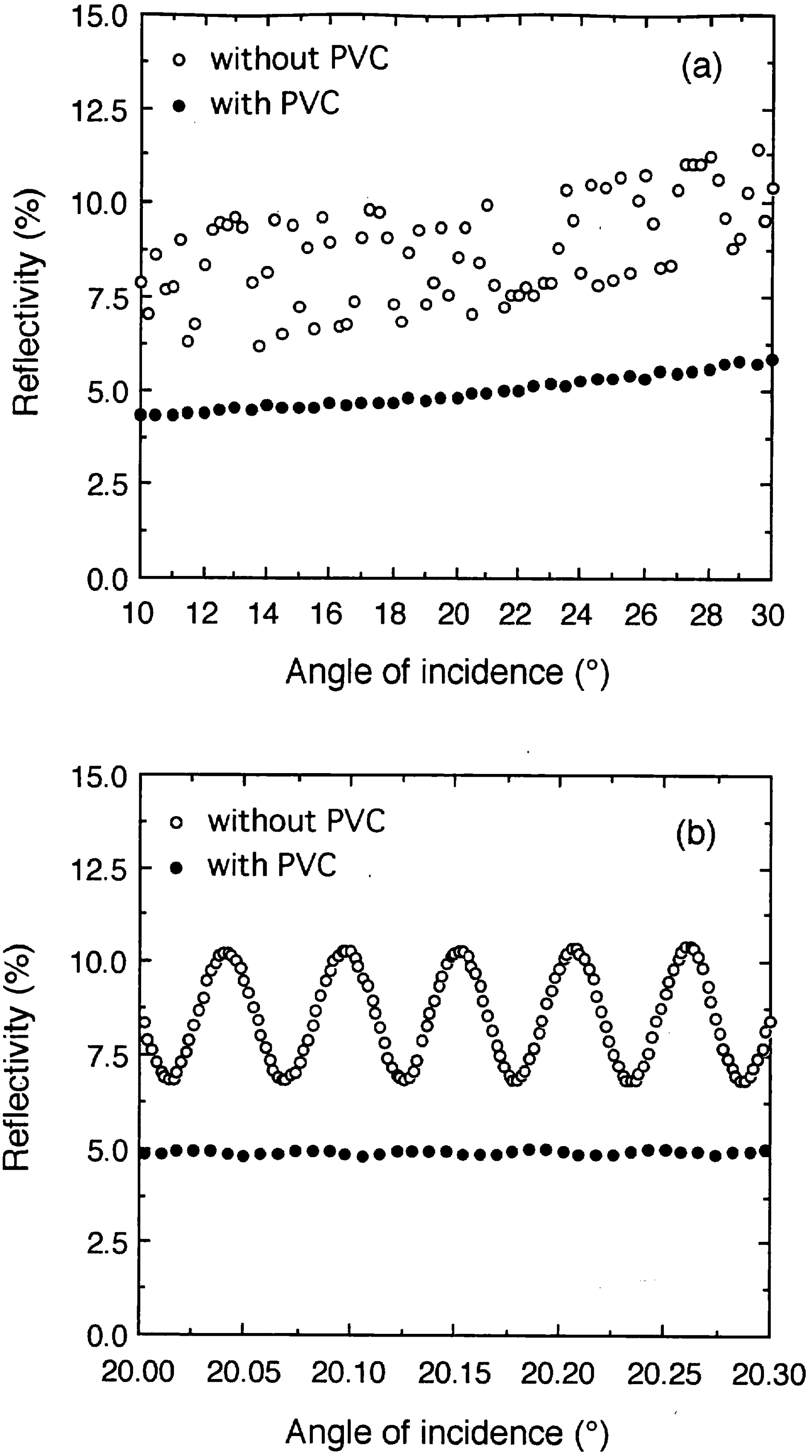

FIGURE 4
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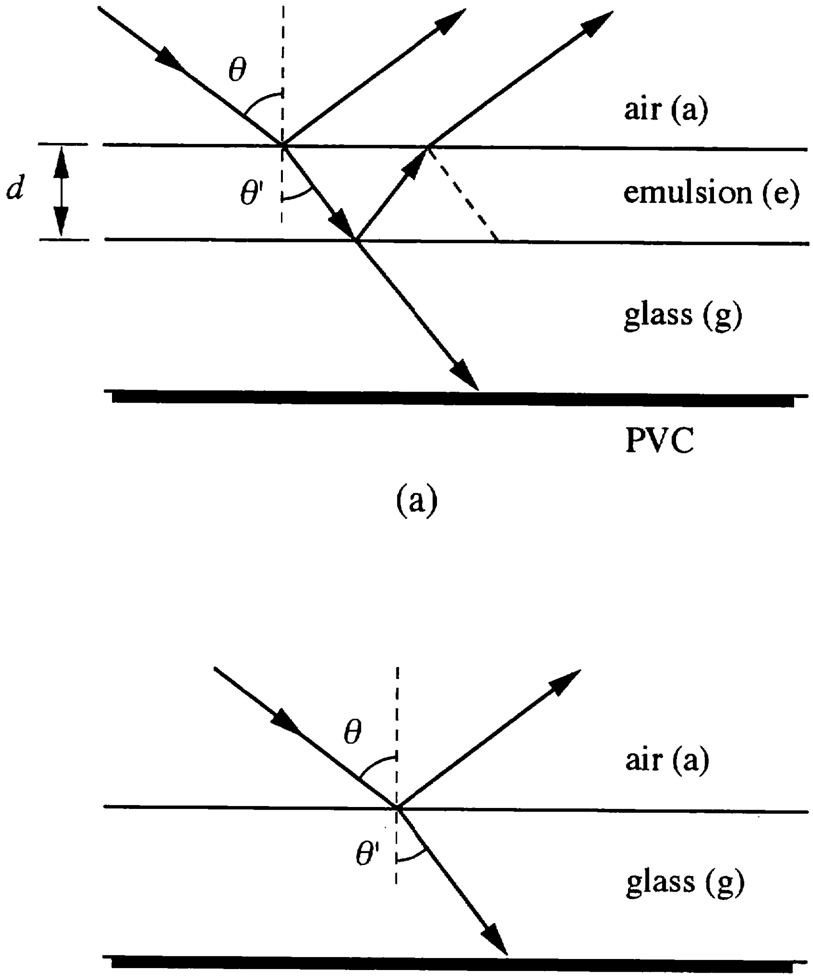

(a)

(b)

FIGURE 5
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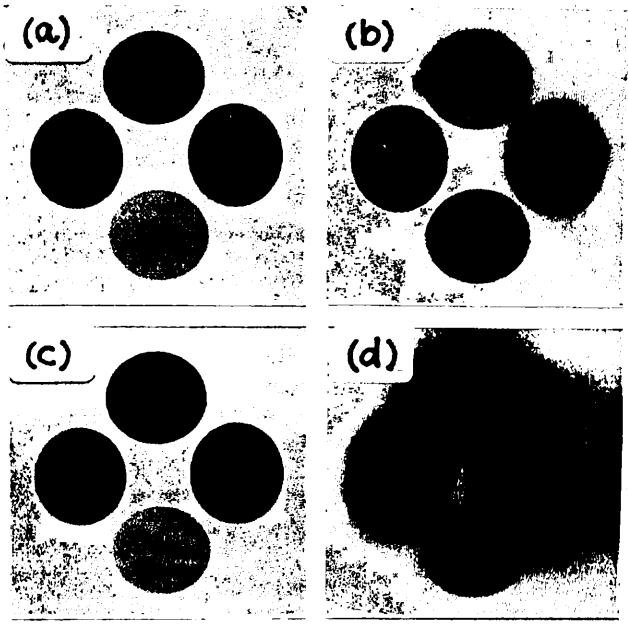

FIGURE 6

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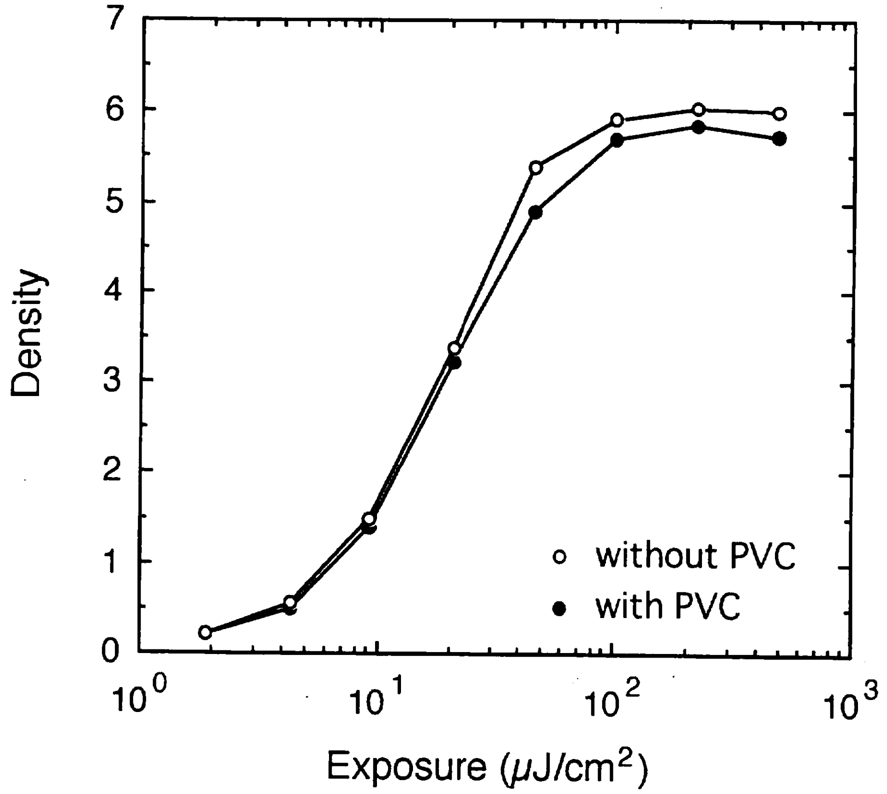

FIGURE 7
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