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- ◄ Proceedings of the 8th International Conference on Energy Planning, Energy Saving, Environmental Education (EPESE '15)

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Planar multicollector solar concentrator

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Abstract: - The analysis of the planar concentrator of light containing mini-collectors and the light guide is carried out. For ensuring capture, the corner of input of light from a mini-collector has to be less internal aperture. For each corner α there is a best value of a refractivity of the light guide, providing formation of light reflected by a reflector symmetrically concerning a light guide axis.

Key-Words: - sunlight, collector, aperture, concentrator, reflection, light guide.

1 Introduction

The concentrated sunlight transferred on the light guide, is perspective for irradiating of the closed rooms by sunlight, receiving electric and/or thermal energy. Searching of efficient devices of collecting and concentration of sunlight is for this purpose conducted. Ways of concentration of sunlight in the light guide can be a little. The best achievement of the last years is creation of concentrators of sunlight with the zero focal distance, having the considerable advantages of miniaturization and design [1-8]. They are federated system of mini-collector and the light guide.

2 Concentration of sunlight in the light guide

In this work the analysis of the planar concentrator of light containing mini-collectors and the light guide is carried out. The mini-collector photon funnel with the tapered light-guide surface, collecting light in the one-dimensional light guide, is shown in figure 1. From a volume focon there is only a thin lateral layer of a surface executed in the form of the two-dimensional light guide that allows reducing the volume and weight by 1-3 orders. The expansion angle

of a funnel can be any. At an expansion angle of 180 degrees, collecting sunlight happens in the concentrator plane.

Light in a photon funnel gets in the beginning to the concentric mini-collectors having in section a form of mini-focons, bounded above a focusing surface with the focal distance equal to height, and two lateral faces.
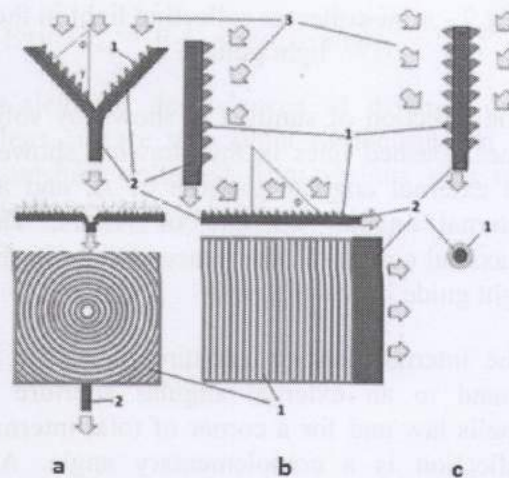
1 - mini-collector 2 - optical fiber, 3 - light direction.

Fig.1 - (a) Photon conical funnel with a plane, (b) filamentous and (c) forms of the

fiber. The arrows indicate the direction of the incoming and outgoing light beams.

In the center of this photon funnel the two-dimensional light guide has funnel or prismatic turn down and passes to the one-dimensional light guide.

The linear mini-collector photon funnel differs from point-like that creates the flat front of distribution of light, providing at the exit a flare in the form of the line, with thickness to the equal thickness of the light guide (Fig.1-b). In Fig.1-c the point-like photon funnel representing the one-dimensional fibro-optical light guide with ring mini-collectors strung on it of light is shown.

The device of a mini-collector and its connection with the light guide it is shown in Fig. 2.
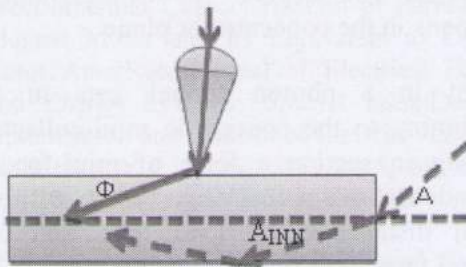

Fig.2 - mini-collector collecting light in the light guide.

The direction of sunlight is shown by solid lines. Dashed lines in this drawing showed an external angular aperture of A, and an internal angular aperture of AINN. The maximal corner of occurrence of light in the light guide is designated Φ.

The internal angular aperture of AINN is bound to an external angular aperture a Snells law and for a corner of total internal reflection is a complementary angle. All these corners depend on the relative refractivity of a core and an envelope. For capture of light of light it has to enter from a mini-collector into the light guide at an angle, smaller an internal angular aperture:

$$\Phi \leq A_{INN} = 90 - \Phi_{max} \qquad (1)$$

The corner of total internal reflection of the light guide with a refractivity of a core of n2 and an envelope of n1 is described by known ratio $\Phi_{max} = asin(n_1/n_2)$. Dependences of a corner of total internal reflection (decreasing curves) and an internal angular aperture (growing curves) from refractivity of a core and an envelope are given in Fig.3.
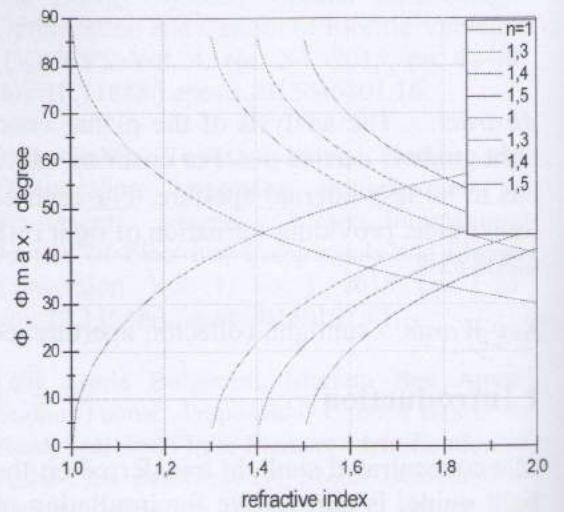

Fig.3 - dependences of a corner of total internal reflection and internal angular aperture on core and envelope refractivity.

Falling or body height of these curves begins at the values equal to a refractivity of an envelope.

3 Calculation of an angular dispersion

For calculation of an angular dispersion of input of light from a mini-collector in the light guide we will consider Fig.4. Here focusing is carried out by the spherical surface having radius of curvature of R.
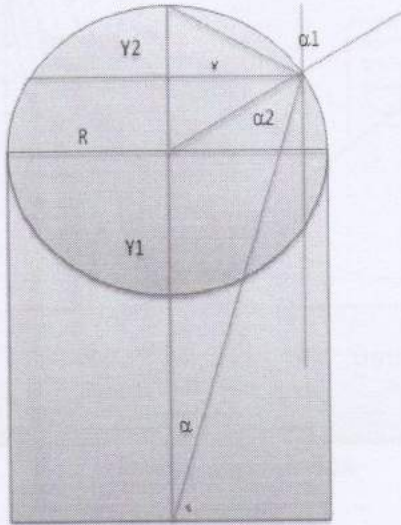
Fig.4 - The scheme of collecting light in a mini-collector with a focusing spherical lens.

Fig.5 - calculated corners of passing of light through a mini-prism.

Apart x from the principal optical axis light falls on a lens at an angle α_1 to radius. The corner of α_2 of a refracted beam is defined by Snells law. The refracted beam forms with the principal optical axis a corner α equal:

$$\alpha = \alpha_1 - \alpha_2 = \alpha_1 - \arcsin(xn_1/Rn_2) \quad (2)$$

Distance from the principal optical axis to a point of falling of light x, radius of curvature of a lens of R and a corner of α_1 are connected by a ratio:

$$x = R \sin\alpha_1 \quad (3)$$

Design values of corners of α_1 (the top curve), α_2 (an average curve) and α (the bottom curve), depending on the relative distance x/R are given in Fig.5.
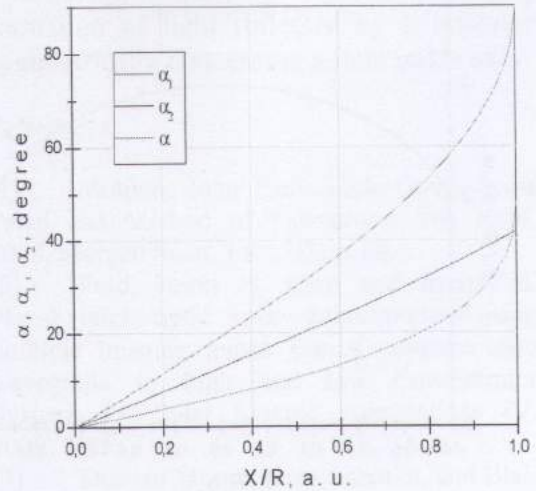
For a lens diameter 2x the corner of collecting light at the basis of a mini-prism will make 2α. For finding of a point of focusing of beams we entered designations y_1, y_2 (Fig.4), equal respectively:

$$y_1 = x/\text{tg}\alpha \quad (4)$$

$$y_2 = R - x/\text{tg}\alpha_1 \quad (5)$$

Then F distance from a lens surface to a point of focusing will make:

$$F = y_1 + y_2 = R + x/\text{tg}\alpha - x/\text{tg}\alpha_1 \quad (6)$$

Calculated dependences of distance on a lens surface to a point of focusing of the sunshine collected from various sites of a lens are given in Fig.6.
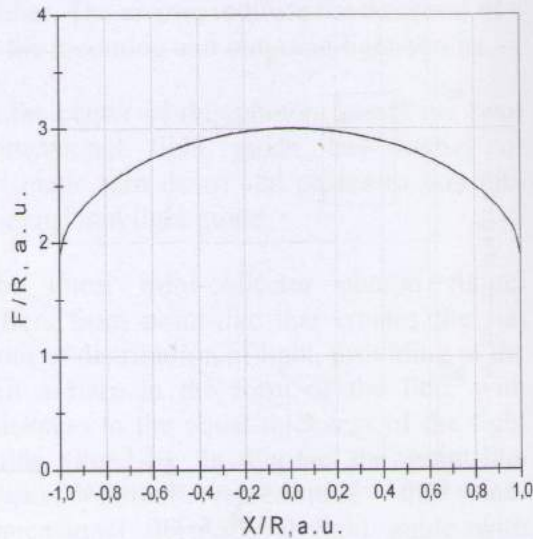
Fig.6 - calculated dependences of a point of focusing of the sunshine collected from various sites of lens.

As we see from the figure 6, lenses collected from various sites sunshine will be focused not in one point (a problem of a spherical aberration). But for almost important central site of a lens from − 0.5 R to + 0.5 R dispersion of F less than 10%.

Light focused on the principal optical axis, it is necessary to redirect with total internal reflection use to the light guide. For calculation of an angular dispersion of input of light from a mini-collector in the light guide we will consider Fig.7. Here the corner of an entering bunch 2α will be initial parameter. To the focal plane the entering bunch will be meeting, and behind it dispersing. For a focal distance we will take a point located apart 3R from a surface of a lens (sphere). When using the central region of a lens of $x < 0.5R$ it is admissible, and α corner thus will be less than $11°$ that is visible from figures 6 and 5, respectively.

Corner between the principal optical axis and a plane mirror we will designate β. Let's number beams, having designated entering 1, 2, 3 and proceeding 1', 2', and 3', respectively. Optimum, the symmetric concerning a light guide axis, the bunch direction in Fig.7 is allocated with color.
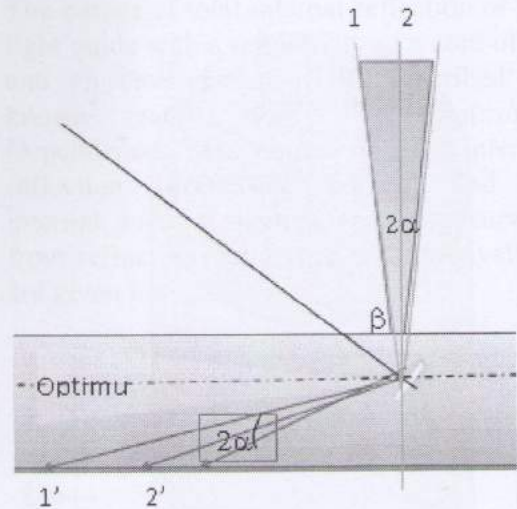

Fig.7 - the scheme of reflection of light in a minicollector.

Let the reflector, in the form of cut in a light guide core, will be flat and is created without a protective shell. Then for almost available range of refractivity of polymers from 1.3 to 1.7 the critical angle Φ_{max} varies from $37°$ to $60°$. At coal between a mirror and a beam 1 it is more Φ_{max} beams 1, 2, 3 will be reflected in the directions 1', 2', 3'. Thus the most refracted beam 3' which we will designate Φ is critical.

$$\Phi = \beta + \alpha \qquad (7)$$

For light capture the corner between a beam Φ and an axis of the light guide has to be less than an internal angular aperture:

$$\Phi = 2 \operatorname{asin}(1/n_2) + 3\alpha - 90 \le A_{INN} \qquad (8)$$

In Fig.8 dependences of a corner Φ from a refractivity of a core of the light guide are shown.
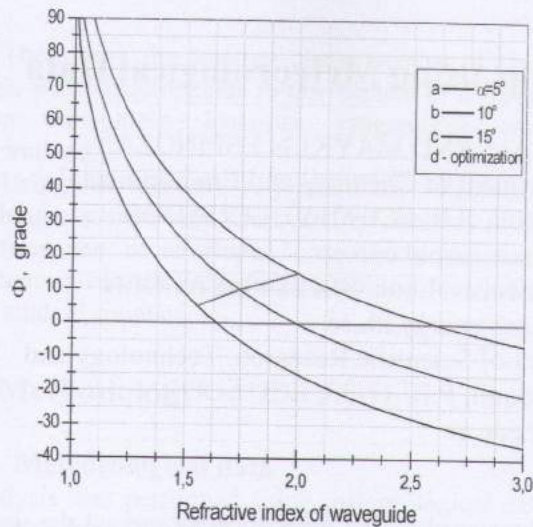
Fig.8 - calculated dependences of a corner of the maximal deviation of light Φ in the light guide from a refractivity of a core of the light guide and a corner of α, collecting light.

Curve a, b, c correspond to values of an aperture of light created in a mini-collector to α equal 5°, 10°, 15°, respectively. Aperture α and refractivity of the light guide are interdependent by a condition of providing the optimum direction of a bunch. For each refractivity of the light guide there is a best value of a corner α providing formation of light reflected by a reflector symmetrically concerning an axis of the light guide. In figure 8 to it there correspond crossings of curve a, b and c with curve d.

For ensuring capture of light it is enough that a corner between the most refracted beam Φ and less A_{INN} was an axis of the light guide.

For the optimized bunch extending in repartitions of a corner from +α to -α from an axis of the light guide has to be carried out by α < A_{INN}.

4 Conclusion

The analysis of the planar concentrator of light containing mini-collectors and the light guide is carried out. For ensuring capture, the corner of input of light from a mini-collector has to be less internal aperture. For each corner of α there is a best value of a refractivity of the light guide, providing formation of light reflected by a reflector symmetrically concerning a light guide axis.

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