(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
2 April 2009 (02.04.2009)

PCT

(10) **International Publication Number**
WO 2009/039798 A2

(51) **International Patent Classification:**
F41H 5/04 (2006.01)

(21) **International Application Number:** PCT/CZ2008/000115

(22) **International Filing Date:** 25 September 2008 (25.09.2008)

(25) **Filing Language:** Czech

(26) **Publication Language:** English

(30) **Priority Data:**
PV 2007-676 26 September 2007 (26.09.2007) CZ
PV 2008-563 15 September 2008 (15.09.2008) CZ

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *of inventorship (Rule 4.17(iv))*

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(54) **Title:** TRANSPARENT ARMOUR SYSTEM AND METHOD FOR ITS MANUFACTURE

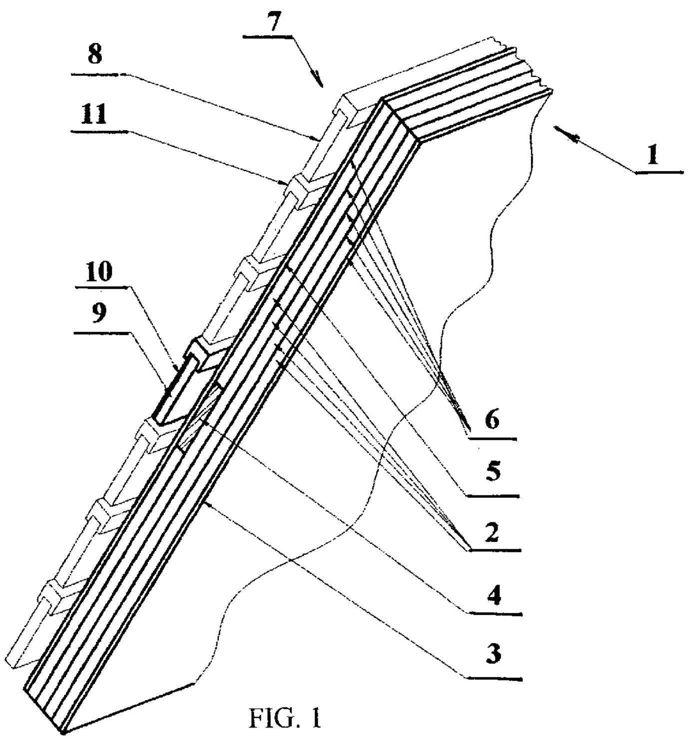

FIG. 1

(57) **Abstract:** The transparent armour system which is designated especially for bullet-proof windows and observation slits of mobile transport armoured vehicles, consisting of transparent armour (1) and external protective movable louver (7) with tilting lamellas (8,9), when between the steel tilting lamellas (8) of the external protective movable louver (7) there is inserted minimally one transparent tilting lamella (9) and the transparent armour (1) is, at least in the area under the transparent tilting lamella (9) and at the same height level, fitted with minimally one transparent hard layer from single crystal sapphire (4). The transparent armour (1) is created by a composite set of sandwiched transparent glass and/or polymer layers (2) that are interconnected with transparent adhesive layers (6), when the transparent hard layer from single crystal sapphire (4) is created by panel segments (4.1) which are laterally interconnected together into minimally one strip, inserted into at least one transparent glass and/or polymer layer (2), and create a part of the window or observation slit on the level of the driver's direct view. The panel segments (4.1) of the transparent hard layer from single crystal sapphire (4) are manufactured parallelly with and/or with angle deviation of up to + 45° from its crystallographic planes whose interplanar distance is 3.1 to 3.9 A

WO 2009/039798 A2

Published:

— *without international search report and to be republished upon receipt of that report*

Transparent armour system and method for its manufacture

Field of the Invention

The invention concerns a transparent armour system which is designated especially for bullet-proof windows and observation slits of mobile transport armoured vehicles, consisting of transparent armour, creating the pane itself of the bullet-proof window or observation slit which is fitted out from the external side with a protective movable louver, created by tilting lamellas, and the method of its manufacture.

Background of the Invention

Currently, mainly transparent armours are utilized for the pane itself of the bullet-proof window or observation slit which are created by composite sets of sandwiched transparent glass layers that are surface-interconnected with adhesive layers, created for example by thermoplastic foils on the basis of polyvinylbutyral (PVB) or polyurethane (PU). The transparent glass layers are usually formed by glass panels, manufactured for example from thick-walled sodium-potassium glass. The basic structure of such transparent armour is known for example from the patent file WO 03/068501 which, in comparison to the similar armours, provides additional protection against possible glass fragments from the interior side of the armour after the impact of small-arms bullet on its external front side. The disadvantage of these types of armours is their relatively low resistance against small-arms bullets with a higher level of piercing capability, which has been so far compensated for by the increase in their thickness, for example up to the thickness of 104 mm. Naturally the increase in this thickness to the stated level results in their extremely high specific weight reaching the value of 250 kg/m^2 which in reality disables the usability of such transparent armours for the majority of mobile transport vehicles, regardless the distorted or impaired transparency of this sandwich transparent armour, composed of up to 12 layers of glass.

In case of new transparent materials, creating the hard frontal layer with a higher ballistic resistance, for example the material based on alumina oxynitride, known under the trade name AION, or on the basis of spinel ($MgAl_2O_4$) or single crystal sapphire, it is their significantly high price in connection with the still necessary considerable thickness and thus specific weight of the armour that prevent their wider usability as transparent armours for mobile transport vehicles.

The so far most resistant transparent armour is also known from the patent file WO 2006/135832, created minimally by one internal glass layer, fitted from the internal side with a transparent polycarbonate layer and from the external side with minimally one transparent ceramic layer from single crystal sapphire. In between these individual layers there are arranged adhesive layers for example from PVB foil or PU foil. For this transparent armour, the layer from single crystal sapphire is manufactured with the method called EFG (Edge-Defined-Film-Fed Growth) as it is described in more detail for example in the patent file WO 2005/100646 including the relevant equipment. Such an armour, created exemplarily by a frontal sapphire layer of the thickness of approximately 8 mm and a rear set of two to three layers of float glass and a polycarbonate or safety foil layers, is sufficiently resistant against small-arms bullets with the medium level of piercing capability e.g. 7.62 x 54R B32 API with the core from hardened steel. Nevertheless, even this transparent armour does not meet the request for its smallest possible thickness with the maximum ballistic resistance against small-arms bullets with the highest level of piercing capability. For this reason, concerning the sufficient protection against these small-arms bullets, such as bullets of the 7.62 x 51 AP8 calibre with the core from tungsten carbide with several times higher piercing capability and significantly bigger hardness in comparison to similar bullets with cores from hardened steel, this armour must be fitted with one or better with more sapphire layers of the total thickness of approximately 40 mm, which even for these so far most resistant versions of armours increases their weight and price above an acceptable level.

That is why the windows or other observation slits especially of various mobile transport armoured vehicles are, to increase the safety of their crew, often covered from the external side with a protective movable louver, created by tilting armour lamellas. The disadvantage of this measure is, however, that when tilting the armour lamellas in case of the danger of the window or observation slit being hit, the crew is prevented completely from looking out of this window or observation slit. This disadvantage is removed, to a certain extent, with an external armour system with tilting armour lamellas in accordance with the patent file US 5,452,641, whose essence lies in the fact that these lamellas are fitted with mirror surfaces at their opposite sides that enable the crew to have at least partial view when the lamellas are partially open. The reflection and refraction of the image on the mirror surface of armour lamellas can, however, result in a certain distortion of the image when observing the external situation and, simultaneously, this solution can contain the danger that in the same manner as the image is reflected, a bullet can be reflected when the window is hit and it gets through the half-open lamellas into the internal space of the vehicle.

The task of the submitted invention is thus the improvement of the current transparent armour systems for bullet-proof windows and observation slits of mobile transport armoured vehicles with the goal to achieve the optimum ratio between the thickness of the window or observation slit pane and its ballistic resistance against even the bullets with the highest existing piercing capability, whilst maintaining its acceptable weight and price.

Summary of the Invention

To a large extent, this task is solved by a transparent armour system designated especially for bullet-proof windows and observation slits of mobile transport armoured vehicles, consisting of transparent armour and external protective movable louver with tilting lamellas, in accordance with the submitted invention, whose essence lies in the fact that between the steel tilting lamellas of the protective louver there is inserted minimally one transparent tilting lamella and the transparent armour is, at least in the area under the transparent tilting lamella and at the same height level, fitted with minimally one transparent hard layer from single crystal sapphire.

Furthermore, the essence of the invention lies in the fact that the transparent armour is advantegously created by a composite set of sandwiched transparent glass and/or polymer layers that are interconnected with transparent adhesive layers, for example on the basis of polyvinylbutyral (PVB) or polyurethane (PU), when the transparent hard layer from single crystal sapphire is created by panel segments, which are laterally interconnected together into minimally one strip, inserted into at least one transparent glass and/or polymer layer, and create a part of the window or observation slit on the level of the driver's or crew's direct view.

The creation of a transparent hard layer from single crystal sapphire in the form of a narrow strip, put in the transparent armour under a transparent tilting lamella, results in considerable savings in costs, however, the transparent hard layer from single crystal sapphire can be, mainly in the cases of smaller windows or observation slits, created for example from panel segments arranged mosaic-like on the whole surface of the transparent armour.

The panel segments of the transparent hard layer from single crystal sapphire are also advantageously created from single crystal sapphire parallelly and/or with angle deviation of up to ± 45° from its crystallographic planes whose interplanar distance is 3.1 to 3.9 Å. The size of these segments from single crystal sapphire can be varied, e.g. 50÷100 x 150÷300 x 7÷20 mm.

This increases the efficiency of dissipating the bullet's kinetic energy by deflecting it from its original direction during its penetration through this sapphire transparent hard layer in the angle of up to 75°. One of the fundamental principles of the invention is thus based on the utilization of only certain specific crystallographic orientation of sapphire in the transparent hard layer.

It is the utilization of these planes or more precisely of these secondary crystallographic orientations of single crystal sapphire contrary to the so far utilized primary planes, marked for example by letters a or c, which enables the above mentioned significant deflection of the bullet and the consequent dissipation of its kinetic energy in the structure of the transparent armour according to the invention. In comparison with the so far existing transparent armours on the basis of glass composition and single crystal sapphire, the utilization of the requisite specific crystallographic orientation of sapphire according to the invention enables the decrease in weight of this transparent ceramic hard sapphire level of 40 to 50 %.

This effect of the secondary crystallographic orientations of single crystal sapphire has not been taken into account so far for the known transparent armour, including the technology state, known in the description, of the stated armour in accordance with file WO 2006/135832. It can be sufficiently proven also by the method of their manufacture since the EFG method, stated in this file, cannot achieve at all these secondary and completely specific crystallographic orientations of single crystal sapphire.

This transparent hard layer with minimal interplanar distance of 3.1 to 3.9 Å between the structural planes of single crystal sapphire creates in the most advantageous version of the invention a hard frontal external side of the armour and, to ease the maintenance, the frontal external side of the armour can be fitted with a thin external cover layer from non-fragmentable polymer material, such as polycarbonate, safety foil or also from glass, put on the external surface of this transparent hard layer. However, in other alternative versions of the invention, this transparent hard layer can be built into the composite set of sandwiched and surface-interconnected transparent glass and/or polymer layers as one of the internal layers, i.e. between the transparent glass layers or between the transparent polymer layers, e.g. from polymethylmethacrylate, or between one transparent glass layer and one transparent polymer layer.

Although the submitted invention takes into account also the variant of more than one such transparent hard layer from single crystal sapphire in the structure of transparent armour, from the point of view of the purpose to be followed and of the almost surprisingly high achieved effect one such transparent hard layer is fully sufficient in comparison with similar armours. The replacement of one such layer in the structure of transparent armour according to the invention with two or more layers, even of the same total thickness, has not shown so far as efficient or well-founded.

In the specific advantageous version of the invention, this transparent hard layer with minimal interplanar distance of 3.1 to 3.9 Å between the crystallographic planes is created from single crystal sapphire parallelly with and/or with angle deviation of up to 45° from one of the structural planes, determined e.g. by Miller's indices $(01\bar{1}2)$; $(10\bar{1}2)$; $(1\bar{1}02)$. These structural planes are marked in some sources also as r planes and the interplanar distances of these planes are 3.479 Å. The r planes are also unequivocally characterized by Wolf-Bragg angle θ of the size of 12° 48′.

On the level of the direct view from the vehicle with the transparent armour system according to the invention there is both minimally one strip of sapphire hard layer in composite sandwich set of the whole window and minimally one transparent tilting lamella of the external protective movable louver. This transparent tilting lamella is manufactured from non-fragmentable polymer, such as polycarbonate (PC), colour-tinted and covered with a non-reflexive layer. This transparent lamella is usually of the same colour as the colour of the steel lamellas surface. The rear and front sides of the transparent armour can be covered with a non-fragmentable polymer layer or safety foil. The steel tilting lamellas of the movable louver have the corresponding level of ballistic resistance pursuant to STANAG 4569 which provides, when added up with the sandwich composition of the window, LEVEL 3a (for bullet 7.62 x 51 AP8) and LEVEL 4.

The advantage of the transparent armour system according to the invention is that in case of a live ammunition attack it decreases the probability of the hit of the transparent lamella and the surface of the window sapphire strip to 6.7% for one bullet, to 0.44 % for the second hit and to 0.03 % for the hit of the third bullet which means a huge contribution to the safety of the vehicle crew. The same colouring of all the lamellas disables the attackers to focus the fire only on the transparent tilting lamella.

The narrowing of the window into only a narrow strip solves also the improved view of the crew after a possible hit of this strip since the rays of the cracks in the lower glasses spread only to a limited extent even in case of a multihit and after tilting up the tilting lamellas of the movable louver the view through the remaining surface of the window is sufficient. The advantage is also the psychologically significantly increased sense of the crew's safety behind the tilted steel lamellas compared to a certain insecurity of the protection by only the large-surface transparent composition of the window.

The higher order costs saving when utilizing sapphire only in the narrow strip is evident and the reduction of the thickness of the whole window sandwich is the result of adding up its protection and the protection by steel lamellas.

The essence of the invention lies furthermore in the method of manufacture of the transparent hard layer from single crystal sapphire of the transparent armour system, whose core lies in the fact that according to the crystallographic orientation of sapphire, selected from its crystallographic planes whose interplanar distance is minimally 3.1 to 3.9 Å, growth nucleus is first made and, consequently, a sapphire single crystal panel or cylinder is manufactured by crystallization in this orientation parallelly with the base, forming after the subsequent cutting, grinding and polishing individual panel segments, which after being assembled together and after being connected to a set of already connected transparent glass and/or polymer layers form together with the external cover layer the front external side of the composite set of the armour.

The sapphire single crystal is advantageously manufactured by the method of horizontally oriented crystallization (HDC). This method of manufacturing is thus based on one of the basic versions of the Bridgman-Stockbarger method of the manufacture of corundum single crystals, consisting of the creation of the conditions for the nucleation of the nucleus single crystal in one point, followed by the growth of the single crystal in the thermal field with the temperature gradient in the direction from the higher temperature zone to the lower temperature zone. The desired thermal gradient is created for example by electrical regulation of heating elements. In the horizontal version of this method, the method of controlled crystallization is combined with the method of zonal melting and the sapphire single crystals are grown in molybdenum boats in vacuum or at decreased pressure 0.2 to 0.3 torr in CO_2 atmosphere. Under this method it is the possible to grow single crystal plates measuring 300x300x40 mm and more.

The sapphire single crystal is advantageously manufactured by the method consisting of the crystal growth on a cooled nucleus that is emerged in melt which is carefully and slowly cooled down in a pot. This method is in essence equal to the HDC method but is based on the Kyropoulos method which is characterized by low thermal gradients (several °C per 1 mm) in the growth and cooling zones, leading to a low density of structural defects. In the course of the growth the growing crystal can be slightly pulled out from the melt, however, it still stays in the pot.

On the contrary, the method of manufacture of the known transparent armour in accordance with WO2006/135832 by the EFG method is based on one of the basic versions of the Stepanov method of corundum single crystals manufacture, when the melt is fed into the crystallization zone by capillary forces, originating between the matrix and melt, and which differs significantly from the HDC method or the Kyropoulos method in the speed of heat dissipation from the crystallization zone. With this method, the ratio of the radiation area to the crystal volume is significantly lower under the otherwise same conditions. For these reasons, it is impossible to achieve with the EFG method, apart form others, significantly lower values of density of structural defects which narrows down the application possibilities of this method.

Brief Description of the Drawings

The invention will be clarified in more detail with drawings of specific examples of transparent armour system version according to the invention where they depict:

Fig. 1 – transparent armour system with transparent armour and protective movable louver in preferred version

Fig. 2 - schematic depiction of an alternative version of only the transparent armour in cross section

Fig. 3 - indication of bullet deflection when hitting the transparent armour when a test is being performed

Fig. 4 - r plane position in the sapphire crystal space

Description of the Prefered Embodiment

Example 1

The transparent armour system in an exemplar version, depicted on Fig. 1, consists of a transparent armour 1 and an external protective movable louver 7 with bullet-proof horizontally arranged steel tilting lamellas 8, between which, on the level of the driver's direct view, is inserted one horizontal transparent tilting lamella 9, replacing in this place the steel tilting lamella 8. Under the transparent tilting lamella 9 there is on the same height level the transparent armour 1, fitted with the transparent hard layer from single crystal sapphire 4.

The transparent armour 1 is formed with a composite set of sandwiched and surface-interconnected four transparent glass layers 2, when the transparent hard layer from single crystal sapphire 4 is created by panel segments which are laterally interconnected together into one strip, inserted into a transparent glass layer 2 on the frontal part of the transparent armour 1. The transparent glass layers 2 are created by glass panels from sodium-potassium float glass which can be chemically hardened or thermally treated. The transparent glass layer 2 on the front side of the transparent armour including the inserted transparent hard layer from single crystal sapphire 4 is fitted with an upper cover layer 5, in this case created by a glass layer, and on the rear side of the transparent armour 1 by a non-fragmentable bottom cover layer 3, in this case created by a polycarbonate layer. In other cases both the upper and bottom cover layers 3,5 can be fomed by a non-fragmentable polymer foil or by a combination of a polycarbonate layer on one side and a polymer foil on the other side of the transparent armour 1.

The panel segments of the transparent hard layer from single crystal sapphire 4 are created from single crystal sapphire parallelly with its structural planes with the interplanar distance of these planes 3.479 Å.

To surface-interconnect all the individual transparent layers 2, 3, 4 and 5, adhesive layers 6 are utilized which are created by transparent thermoplastic foils.

The tilting lamellas 8,9 are fastened in the external protective louver with the aid of holders 11 and are controllable from the internal space of the vehicle. The transparent tilting lamella 9 is manufactured from non-fragmentable polymer, colour-tinted and covered with a non-reflexive layer 10, the colour of this transparent lamella 9 is identical with the surface colour of the steel tilting lamellas 8.

Example 2

The transparent armour system according to the invention in an alternative version, corresponding to Fig. 1, consists as in the first exemplar version also of the transparent armour formed with a composite set 1 of sandwiched and surface-interconnected four transparent glass layers 2 and of the external protective movable louver 7 with bullet-proof horizontally arranged steel tilting lamellas 8, between which, on the level of the driver's direct view, is inserted one horizontal transparent tilting lamella 9 , under which there is on the same height level the transparent armour 1, fitted with the transparent hard layer from single crystal sapphire 4. The composite set of the transparent armour 1 is also identical with the first version example, only, as shown above, the bottom cover layer 3 is created with the polycarbonate layer and the upper cover layer 5 with a polymer foil.

The difference from the first exemplar version of the invention thus lies in the fact that the panel segments of the transparent hard layer from single crystal sapphire 4 are manufactured with angle deviation of + 30° from its crystallographic planes whose interplanar distance is 3.479 Å .

The advantage of this solution is, on one hand, an easier dissipation of the bullet kinetic energy in the medium with thinner atom density of the marked crystallographic planes and, on the other hand, their better geometry regarding the entry of the bullet into their bundle.

Example 3

Fig. 2 then schematically depicts an alternative version of the transparent armour 1 itself of the transparent armour system, consisting also of the composite set 1 of sandwiched and surface-interconnected two transparent glass layers 2. The transparent glass layers 2 are created by glass panels from sodium-potassium glass, one with thickness of 12 mm and the other one with thickness of 8 mm and covered in the rear part with a safety bottom cover layer 3 from polyester foil.

Furthermore, the transparent armour 1 is fitted with one full-area transparent hard layer from single crystal sapphire 4 with thickness of 25 mm, set on the transparent glass layer 2 with thickness of 12 mm. This transparent hard layer from single crystal sapphire 4 is created from individual laterally connected panel segments (4.1) arranged mosaic-like from single crystal sapphire parallelly with its structural planes, determined by Miller's indices ($1\bar{1}02$), marked further in Fig. 4 as the r planes, with the interplanar distance of these planes 3.479 Å and angle θ with size of 12° 48′. To be complete, Fig. 4 depicts also the a, c planes used so far.

On the external surface of the full-area transparent hard layer from single crystal sapphire 4 there is set up the glass cover layer 5 with the thickness of 2 mm, creating the frontal external side of the composite set 1. The rear side of the composite set 1 is created by the already mentioned bottom cover layer 3 from safety foil with the thickness of approximately 1.0 mm which is set up on the internal transparent glass layer 2.

To interconnect all the individual transparent layers 2, 3, 4 and 5, adhesive layers 6 are utilized which are created with PVB thermoplastic foils with the width of 0.65 mm.

Thus the total thickness of the transparent armour 1 is approximately 50 mm and, as it can be further seen from Fig. 3, this armour 1 is sufficiently resistant against the bullet 7.62x51 AP8 (WC). This resistance is assisted significantly by the deflection of the bullet by the angle of up to 75°, as it is depicted in this figure.

The composite set of the transparent armour 1 according to the invention is principally made utilizing common methods. The essence of its method of manufacture according to the invention lies only in the creation of the transparent hard layer from single crystal sapphire 4, when depending on the crystallographic orientation of the sapphire, selected from its crystallographic planes whose interplanar distance is 3.479 Å, there is first made growth nucleus and subsequently cylindrical or flat sapphire single crystal is made by crystallization from the melt, forming after the subsequent cutting, grinding and polishing parallelly or under an angle, corresponding to the selected angle deviation from these crystallographic planes, i.e. for the second example of version under the angle of 30°, individual panel segments (4.1). These individual panel segments (4.1) then after being assembled together and after being connected to a set of already connected transparent glass layers 2 form together with the cover glass layer 5 the front external side of the armour. The sapphire single crystal is manufactured from its melt by the Kyropoulos method.

PATENT CLAIMS

1. The transparent armour system which is designated especially for bullet-proof windows and observation slits of mobile transport armoured vehicles, consisting of transparent armour (1) and external protective movable louver (7) with tilting lamellas (8,9), **characterised by the fact** that between the steel tilting lamellas (8) of the external protective movable louver (7) there is inserted minimally one transparent tilting lamella (9) and the transparent armour (1) is, at least in the area under the transparent tilting lamella (9) and at the same height level, fitted with minimally one transparent hard layer from single crystal sapphire (4).

2. The transparent armour system according to claim 1, **characterised by the fact** that the transparent armour (1) is created by a composite set of sandwiched transparent glass and/or polymer layers (2) that are interconnected with transparent adhesive layers (6), when the transparent hard layer from single crystal sapphire (4) is created by panel segments (4.1) which are laterally interconnected together into minimally one strip, inserted into at least one transparent glass and/or polymer layer (2), and create a part of the window or observation slit on the level of the driver's direct view.

3. The transparent armour system according to claim 2, **characterised by the fact** that the panel segments (4.1) of the transparent hard layer from single crystal sapphire (4) are manufactured parallelly and/or with angle deviation of up to ± 45° from its crystallographic planes whose interplanar distance is 3.1 to 3.9 Å .

4. The transparent armour system according to claim 3, **characterised by the fact** that the panel segments (4.1) of the transparent hard layer from single crystal sapphire (4) with the minimal interplanar distance of 3.1 to 3.9 Å between the crystallographic planes are created from single crystal sapphire parallelly and/or with angle deviation of up to ± 45° from its crystallographic planes, determined e.g. by Miller's indices $(01\bar{1}2)$; $(10\bar{1}2)$; $(1\bar{1}02)$.

5. The transparent armour system according to at least one of the claims 2 to 4, **characterised by the fact** that the transparent hard layer from single crystal sapphire (4), created with the panel segments (4.1) which are laterally interconnected together into a strip, is inserted into a transparent glass and/or polymer layer (2) on the front side of the transparent armour (1).

6. The transparent armour system according to at least one of the previous claims, **characterised by the fact** that the front side of the transparent armour (1) is fitted with the upper covering layer (5).

7. The transparent armour system according to at least one of the previous claims, **characterised by the fact** that the transparent tilting lamella (9) of the external protective louver (7) is manufactured from non-fragmentable polymer, colour-tinted and covered with a non-reflexive layer (10).

8. The method of manufacture of the hard transparent layer from single crystal sapphire (4) of the transparent armour system (1) according to claim 1 **characterised by the fact** that according to the crystallographic orientation of sapphire, selected from its crystallographic planes whose interplanar distance is minimally 3.1 to 3.9 Å, growth nucleus is first made and, consequently, a sapphire single crystal panel or cylinder is manufactured by crystallization in this orientation parallelly with the base, forming after the subsequent cutting, grinding and polishing individual panel segments (4.1), which after being assembled together and after being connected to a set of already connected transparent glass and/or polymer layers (2) form together with the external cover layer (5) the front external side of the composite set of the armour (1).

9. The method of manufacture of the transparent armour according to claim 8, **characterised by the fact** that sapphire single crystal is manufactured by the method of horizontally oriented crystallization (HDC).

10. The method of manufacture of the transparent armour according to claim 8, **characterised by the fact** that sapphire single crystal is manufactured by the method according to Kyropoulos.

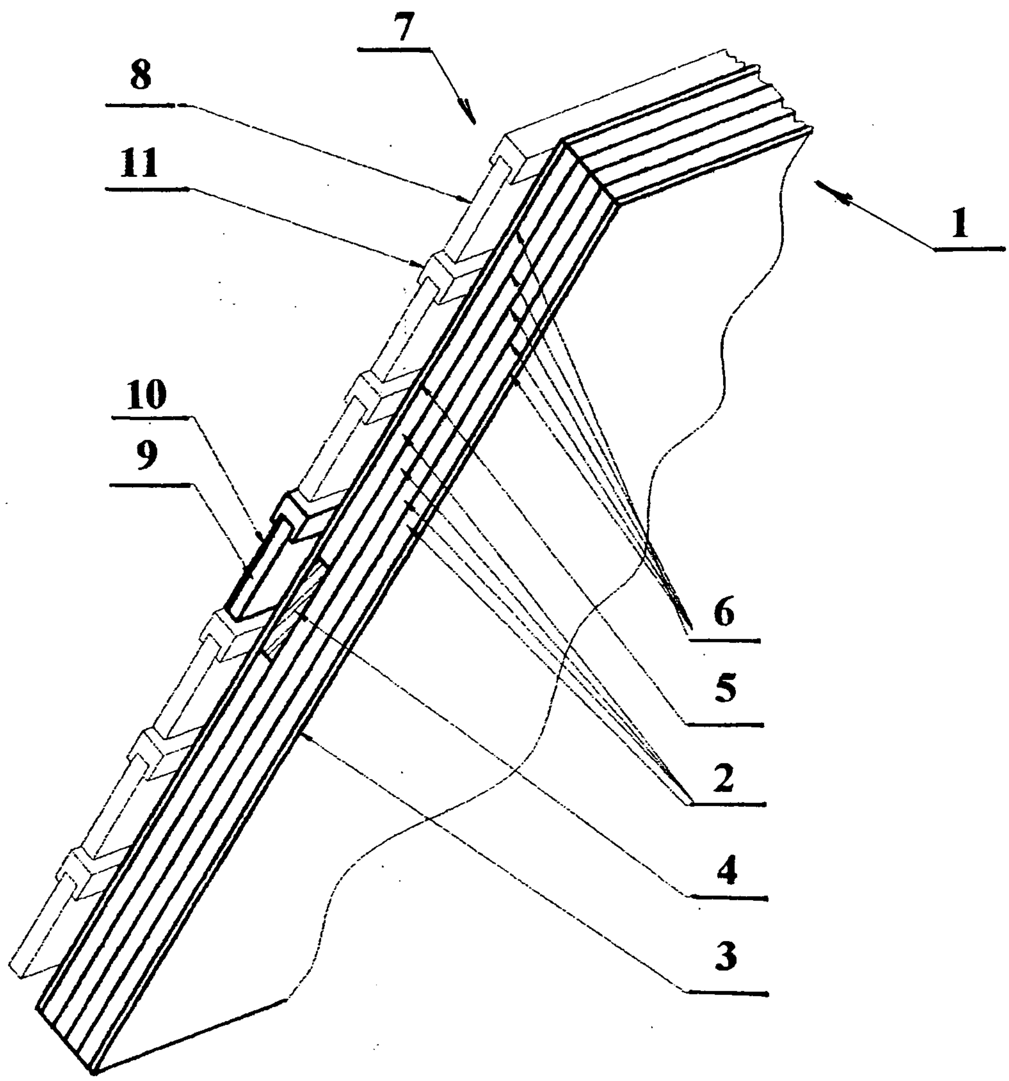

FIG. 1

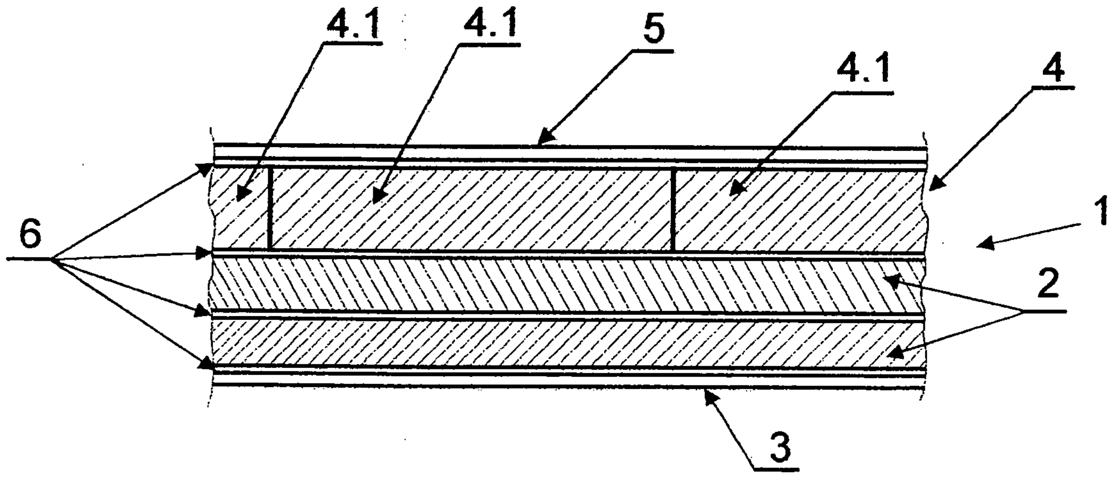

FIG. 2

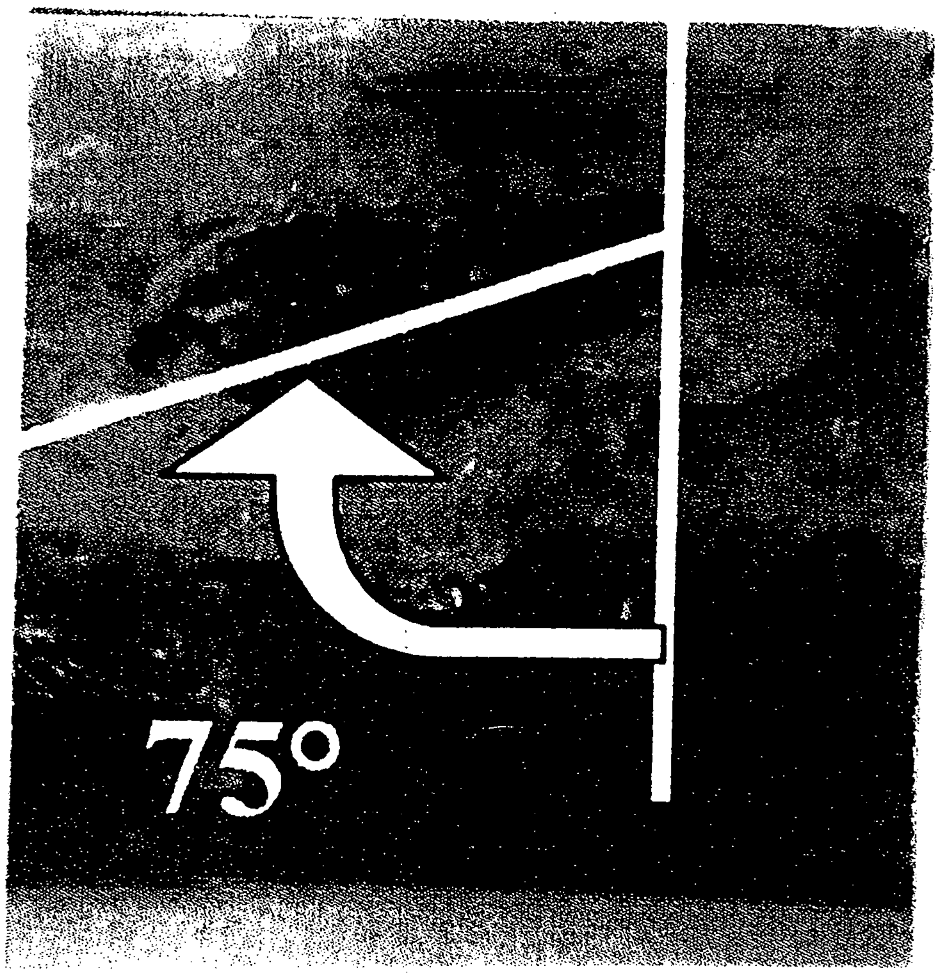

FIG. 3

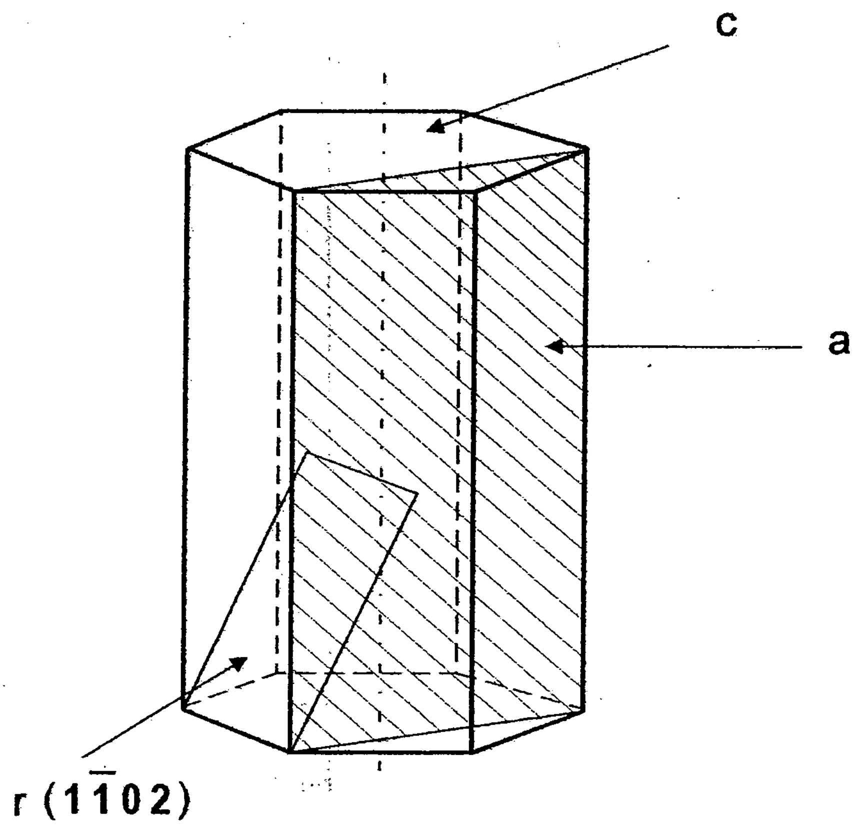

FIG. 4