CLAIMS

1. A method to create a colored surface, comprising the steps of:

(a) anodizing a substrate in an anodizing bath comprising phosphoric acid, at a constant temperature and a constant voltage for a first time period to develop an anodizing layer ~~that includes a barrier layer~~having one or more main pores; wherein each of the one or more main pores includes one or more side pores; wherein the anodizing layer includes a barrier layer;

(b) reducing the constant voltage applied to the anodizing bath for a second time period to change a thickness of the barrier layer and change a width of the one or more main pores in the ~~—~~anodizing layer;

(c) plating the substrate in a plating bath to at least partially fill the one or more main pores and the one or more side pores and develop a plasmonic surface at a first current that is increased over a ~~——~~third time period in accordance with a current profile of the plating bath; ~~and~~

(d) plating the substrate in the plating bath at a second current for a fourth time period~~.~~ to partially fill the one or more main pores and the one or more side pores with metal nanorods; and

(e) applying a sealing layer over the one or more main pores of the anodizing layer and forming an air gap between the metal nanorods and the sealing layer.

2. The method of claim 1, wherein the substrate comprises an aluminum alloy.

~~3. The method of claim 1, wherein in step (a) the anodizing bath further comprises copper sulfate and a chelating agent.~~

~~4~~3. The method of claim 1, wherein in step (a) the constant temperature is a temperature between 20 degrees Celsius and 40 degrees Celsius.

~~5~~4. The method of claim 1, wherein in step (a) the constant voltage is a voltage between 60 Volts and 280 Volts, with a maximum current density of 2 amperes per square decimeter.

~~6~~5. The method of claim 1, wherein in step (b) the constant voltage is ~~-~~reduced by 50%, and the second time period comprises between 2 and 10 minutes~~.~~, and then reduced by a further 50% for a third time period of between 1 and 4 minutes.

~~7. The method of claim 1, further comprising in step (b): reducing the constant voltage applied to the anodizing bath a second time before the plating.~~

~~8~~6. The method of claim 1, wherein in step (b) the voltage applied to the anodizing bath is reduced to (i) reduce the thickness of the barrier layer, and (ii) to increase the width of the one or more main pores in the anodizing layer.

~~9. The method of claim 1, wherein the barrier layer is positioned intermediate the substrate and the anodizing pores.~~

~~10. The method of claim 1 wherein in step (d) the plating of the substrate partially fills the pores in the anodizing layer with metal nanorods.~~

~~11. The method of claim 10 further including the step of applying a sealing layer over the pores of the resulting anodizing layer.~~

~~12. The method of claim 10 or claim 11 wherein the step of applying a sealing layer over the pores forms an air gap between the pores and the sealing layer.~~

~~13~~7. A method to create a plasmonic colored surface, comprising the steps of:

(a) anodizing an aluminum alloy substrate in an anodizing bath comprising phosphoric acid, at a constant temperature and a constant direct or pulsed current and/or voltage for a first time period to develop an anodizing layer of between 2 and 10 microns thick~~,~~ having one or more main pores; wherein the one or more main pores include one or more side pores; wherein the anodizing layer includes a barrier layer;

(b) reducing the constant direct or pulsed current and/or voltage applied to the anodizing bath for a second time period to change a thickness of the barrier layer and change a width of the one or more main pores in the anodizing layer;

(c) plating the aluminum alloy substrate in a plating bath at a first current that is increased over a third time period in accordance with a direct current (DC) plating current profile of the plating bath;

(d) plating the aluminum alloy substrate in the plating bath at a second current for a fourth time period to at least partially fill the one or more main pores and the one or more side pores in the anodizing layer and develop a plasmonic surface; and

(e) sealing the one or more main pores of the anodizing layer resulting in an air gap formed between the one or more main pores and a sealing layer.

~~14~~8. The method of claim ~~13~~7, wherein in step (a) the anodizing bath comprises 50-600 milliliters per liter (ml/L) of phosphoric acid, 1 -15 ml/L of sulfuric acid, and 1 -10 grams per liter (g/L) of ~~HOOCCOOH~~oxalic acid.

~~15~~9. The method of ~~13~~ claim 7, wherein in step (a) the anodizing bath further comprises ~~0~~1 to 5 weight percent of copper sulfate and ethylenediaminetetraacetic acid (EDTA).

~~16. The method of claim 13, wherein in step (a) a pulsed directed current is applied to the anodizing bath.~~

~~17~~10. The method of claim ~~13~~7, wherein in step (c) the plating bath comprises a semi-bright nickel bath with a nominal plating current of between 2 amperes per square decimeter (A/dm^2) and 4 A/dm^2.

~~18. The method of claim 17, wherein in step (d) the second current is 1% to 20% of the nominal plating current of the plating bath.~~

~~19. The method of claim 17 or claim 18, wherein the first current is between 10% and 50% of the second current.~~

~~20. The method of claim 13, wherein the barrier layer is positioned intermediate the substrate and the anodizing pores.~~

~~21~~11. The method of claim ~~13~~7, wherein in step (d) the plating of the substrate partially fills the pores in the anodizing layer with metal nanorods.

~~22. The method of claim 13 wherein in step (e) the step of sealing the pores of the anodizing layer, an air gap is formed between the pores and the sealing layer.~~

~~23~~12. A method, comprising the steps of:

(a) ~~optionally~~ pre-treating an aluminum alloy substrate;

(b) activating the aluminum alloy substrate;

(c) anodizing the aluminum alloy substrate in an anodizing bath comprising phosphoric acid, at a constant temperature and a constant voltage for a first time period, to develop an anodizing layer having one or more main pores; wherein the one or more main pores include one or more side pores; that includes a barrier layer;

(d) reducing the constant voltage applied to the anodizing bath for a second time period to change a thickness of the barrier layer and change a width of the one or more main pores in the anodizing layer;

~~(e) rinsing the aluminum alloy substrate to further reduce the thickness of the barrier layer;~~

(~~f~~e) plating the aluminum alloy substrate in a plating bath via multiple plating stages to deposit ~~a coloring~~ metal nanorods into the one or more main pores and the one or more side pores of the anodizing layer; and

(g) sealing the one or more main pores of the anodizing layer resulting in an air gap formed between the one or more main pores and a sealing layer.

~~24~~13. The method of claim ~~23~~12, wherein the pre-treating step (a) modifies the average roughness (Ra) of the aluminum alloy substrate and comprises~~;~~:

~~-~~degreasing the aluminum alloy substrate in an alkaline bath;

~~-~~roughening the aluminum alloy substrate in a solution of phosphoric acid, polyethylene glycol, sulfuric acid, and hydrofluoric acid; and etching the aluminum alloy substrate in a nitric acid solution~~.~~

~~25. The method of claim 24, wherein an average roughness (Ra) of the aluminum alloy substrate is~~ to develop an Ra of between 0.4 and 1~~-~~.8.

~~26~~14. The method of claim ~~23~~12, wherein in step (~~f~~e) the multiple plating stages comprise: a first plating stage that applies a first current that is increased over a third time period in accordance with a current profile of the plating bath; and

a second plating stage that applies a constant second current for a fourth time period.

~~27. The method of claim 23, wherein the barrier layer is positioned intermediate the substrate and the anodizing pores.~~

~~28. The method of claim 23 wherein in step (g) the step of sealing the pores of the anodizing layer, an air gap is formed between the pores and the sealing layer.~~

~~29~~15. A coated structure produced according to ~~the process~~ a method as claimed in ~~any one of claims 1 to 12~~ claim 1~~.~~

~~30. A coated structure produced according to the process as claimed in any one of claims 13 to 22.~~

~~31. A coated structure produced according to the process as claimed in any one of claims 23 to 29.~~

~~32. A coated structure~~ comprising:

• a metallic substrate layer;

• a barrier layer intermediate the substrate layer and an anodized pore;

• the anodized layer having a plurality of spaced apart pores extending through the anodized layer towards the barrier layer,

~~• each spaced apart pore having a variable width along its pore length.~~

- an anodized layer having a plurality of side pores joining the spaced about pores at periodic intervals
- a coating surface layer.

~~33. The coated structure as claimed in claim 33, wherein the width of each spaced apart pore is narrower at the pore end proximate the base layer and wider at the other end of the pore.~~

~~34~~16. The coated structure as claimed in claim ~~33 or claim 34~~ 15, wherein at least some of the spaced apart pores and associated side pores are partially filled with metal~~.~~ to develop color through plasmonic effects.

~~35. The coated structure as claimed in any one of claims 33 to 35 wherein a coating layer is present over the anodized layer.~~

~~36~~17. The coated structure as claimed in claim ~~36~~15 wherein the coating surface layer seals the pores through the anodized layer~~.~~ and creates an airgap along the length of at least some of the space about pores and side pores.

~~37. The coated structure as claimed in claim 36 or claim 37 wherein an air gap is present at an intermediate point along the length of at least some of the spaced apart pores and the coating layer.~~

18. The method of claim 12 wherein in step (f) the step of sealing the pores of the anodizing layer, the air gap is maintained between the pores and a sealing layer by a nanoparticle configured to plug the pores.

19. A method to create a plasmonic colored surface, comprising the steps of:

(a) anodizing a substrate in an anodizing bath comprising phosphoric acid, at a constant temperature and a constant voltage for a first time period to develop an anodizing layer having one or more main pores; wherein each of the one or more main pores include one or more side pores; wherein the anodizing layer includes a barrier layer;

(b) reducing the constant voltage applied to the anodizing bath for a second time period to change a thickness of the barrier layer and change a width of the one or more main pores in the anodizing layer;

(c) plating the substrate in a plating bath to fill or partially fill the one or more main pores and the one or more side pores and develop a plasmonic surface, at a first current that is increased over a third time period in accordance with a current profile of the plating bath;

(d) plating the substrate in the plating bath at a second current for a fourth time period; and

(e) sealing the one or more main pores of the anodizing layer resulting in an air gap formed between the one or more main pores and a sealing layer.