Claims

1. A substrate coated with a multi-layer coating, comprising in order from the outside towards the substrate:

a first functional ta-C-containing layer of hardness 2000 HV or greater,

a second functional ta-C-containing layer of hardness 1200 HV or greater,

a first intermediate layer comprising tungsten carbide,

a second intermediate layer comprising chromium tungstide, and

a further intermediate layer comprising chromium and adjacent the substrate,

wherein the ta-C has a hydrogen content less than 10% and an sp^2 content less than 30%;

wherein the first functional layer has a hardness at least 200 HV greater than the second functional layer; and

wherein (1) the Young's modulus or (2) the hardness or (3) both the Young's modulus and the hardness independently stay the same or increase from layer to layer from the second intermediate layer to the first functional layer.

2. A coated substrate according to claim 1, wherein the coating comprises one or more further functional layers comprising ta-C between the second functional layer and the first intermediate layer.

3. A coated substrate according to any preceding claim, wherein the ta-C has a hydrogen content of 5% or less and an sp^2 content of 20% or less.

4. A coated substrate according to any preceding claim, wherein the ta-C has a hydrogen content of 2% or less and an sp^2 content of 15% or less.

5. A coated substrate according to any preceding claim, wherein the substrate is metallic, a metal or an alloy, e.g. steel.

6. A coated substrate according to any preceding claim, wherein the substrate is steel or a variety of steel (e.g. steel, stainless steel, HSS, tool steel and alloy steel).

7. A coated substrate according to any preceding claim, wherein the Young's modulus increases over a set of three adjacent layers in the coating.

8. A coated substrate according to any preceding claim, wherein the Young's modulus increases from an adhesion or seed layer to the final, uppermost functional layer.

9. A coated substrate according to claim 7 or claim 8, wherein the average increase in the Young's modulus is 10GPa per layer, or more.

10. A coated substrate according to any preceding claim, wherein the coating has a hardness of at least 2000 HV.

11. A coated substrate according to any preceding claim, wherein the coating has a hardness of at least 2500 HV.

12. A coated substrate according to any preceding claim, wherein the coating has a hardness of at least 3000 HV.

13. A coated substrate according to any preceding claim, wherein the coating has a hardness of at least 4000 HV.

14. A coated substrate according to any preceding claim, wherein the hardness increases over any set of three adjacent layers in the coating.

15. A coated substrate according to claim 13 or 14, wherein the average increase in hardness is at least 300 HV per layer.

16. A coated substrate according to claim 13 or 14, wherein the average increase in hardness is at least 400 HV per layer.

17. A coated substrate according to any preceding claim, wherein the hardness of the functional layer adjacent the first intermediate layer is 1600 HV or more.

18. A coated substrate according to any preceding claim, wherein the coating has a total thickness of 5 microns or less.

19. A coated substrate according to any preceding claim, wherein the coating has a total thickness of 3 microns or less.

20. A coated substrate according to any preceding claim, wherein the coating has a total thickness of 2 microns or less.

21. A coated substrate according to any preceding claim, wherein each layer of the coating has a thickness of 1 micron or less.

22. A coated substrate according to any preceding claim, wherein each layer of the coating has a thickness of 0.7 microns or less.

23. A coated substrate according to any preceding claim, wherein the substrate is selected from tools, cutting tools, tooling, industrial machines and components therefor.

24. A coated substrate according to any preceding claim, wherein the substrate is an engine component.

25. A coated substrate according to claim 24, wherein the substrate is selected from a piston ring, a piston pin, a cam shaft, a tappet, a lift valve and an injection nozzle.

26. A method of making a coated substrate according to any preceding claim, comprising providing the substrate, and coating onto the substrate, in order:

a further intermediate layer comprising chromium,

a second intermediate layer comprising chromium tungstide,

a first intermediate layer comprising tungsten carbide,

a second functional ta-C containing layer of hardness 1200 HV or greater,

a first functional ta-C containing layer of hardness 2000 HV or greater,

wherein the ta-C has a hydrogen content less than 10% and an sp^2 content less than 30%;

wherein the first functional layer has a hardness at least 200 HV greater than the second functional layer;;

wherein (1) the Young's modulus or (2) the hardness or (3) both the Young's modulus and the hardness independently stay the same or increase from layer to layer from the second intermediate layer to the first functional layer.

27. A method according to claim 26, wherein the intermediate layers are deposited by sputtering.

28. A method according to claim 26 or claim 27, wherein the functional layers are deposited by PVD, e.g. sputtering or CVA.

29. A method according to claim 28, wherein the functional layers are deposited by FCVA.