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(54) Title: A COATED CUTTING TOOL AND A METHOD FOR ITS PRODUCTION

(57) Abstract: The invention relates to a coated cutting tool comprising a substrate of cemented carbide, cermet, cBN, ceramics or HSS, with a coating comprising a nitride layer which is a High Power Impulse Magnetron Sputtering (HIPIMS)-deposited layer of a nitride of one or more of Ti, Zr, Hf, V, Ta, Nb, Cr, Si and Al, and a HIPIMS-deposited oxide layer being an $(Al_aMe_{1-a})_2O_3$ layer, $0.05 \leq a \leq 1$, wherein Me is one or more of Ti, Mg, Ag, Zr, Si, V, Fe, Hf, B and Cr, the oxide layer is situated above the nitride layer. Also, a method is disclosed for producing a coated cutting tool comprising said nitride layer and oxide layer, the nitride layer and the oxide layer are deposited by a HIPIMS process.



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A COATED CUTTING TOOL AND A METHOD FOR ITS PRODUCTION

The present invention relates to a coated cutting tool comprising a body of cemented carbide, cermet, HSS or ceramics with a PVD coating comprising a metal nitride and and an aluminum containing oxide. The present invention also relates to a
5 method for its production and its use for machining of ISO-S materials.

Introduction

10 There is a continuous desire to improve cutting tools for metal machining so that they last longer, withstand higher cutting speeds and/or other increasingly demanding cutting operations. Commonly, a cutting tool for metal machining comprises a hard substrate material such as cemented carbide which has a thin hard coating usually deposited by either chemical vapour deposition (CVD) or physical vapour
15 deposition (PVD). More specifically, the cutting tool may be in the form of an insert for turning or milling, a drill or an endmill.

Layer combinations of a metal nitride, for example (Ti,Al)N, and an oxide layer, such as aluminum oxide are known in general. Nevertheless, nitride and oxide layers will perform very differently in a machining operation depending on various properties
20 and parameters such as crystallinity, hardness, density, way of manufacture etc..

Hard coatings for cutting tools can be deposited by various methods which generally can be divided into two main groups, chemical vapour deposition (CVD) and physical vapour deposition (PVD). Within the group of PVD deposition there are several sub-groups such as cathodic arc deposition, ion plating and reactive sputtering.
25 Arc-deposited coatings and sputtered coatings are in the art of PVD coatings seen as subgroups of PVD coatings having different properties. A special type of sputtering which has quite recently been developed is High Power Impulse Magnetron Sputtering (HIPIMS). The unique structure and properties of HIPIMS-deposited layers are very difficult to define and quantify from other sputtered coatings by ordinary available
30 physical measurements. In the art of PVD coatings the term HIPIMS-coating is therefore in itself used as a definition of this type of PVD coating distinguishable from other types of PVD coatings.

Machining of ISO-S materials such as titanium and heat resistant super alloys (HRSA) puts special demands on the cutting tool. The ISO-S materials have, for
35 example, poor heat conductivity which generates high temperatures during machining creating wear. Also, the tendency of strong work hardening of the ISO-S materials lead

to risk of built up edge on the cutting tool which effects the quality of the workpiece such as poor surface finish. Furthermore, when machining titanium problems due to the high reactivity of titanium may occur especially at the high temperatures created during machining. Typically smearing is connected to the formation of built up edge.

5 The object of the present invention is therefore to provide a coated cutting tool which out-performs previously ones used in machining of ISO-S materials in terms of reduced amount of built up edge and therefore enabling higher cutting speeds and/or giving longer tool life time.

10 The invention

The object of the invention has surprisingly been achieved by a coated cutting tool comprising a substrate of cemented carbide, cermet, cBN, ceramics or HSS, with a coating comprising a nitride layer which is a High Power Impulse Magnetron Sputtering (HIPIMS)-deposited layer of a nitride of one or more of Ti, Zr, Hf, V, Ta, Nb, Cr, Si and
15 Al, and a HIPIMS-deposited oxide layer being an $(Al_aMe_{1-a})_2O_3$ layer, $0.05 \leq a \leq 1$, wherein Me is one or more of Ti, Mg, Ag, Zr, Si, V, Fe, Hf, B and Cr, the oxide layer is situated above the nitride layer.

The thickness of the nitride layer is suitably 0.5-5 μm , or 1-4 μm .

The thickness of the oxide layer is suitably 0.1-5 μm , or 0.3-3 μm , or 0.5-1 μm .

20 The nitride layer can be represented by the general formula $Ti_bZr_cHf_dV_eTa_fNb_gCr_hSi_iAl_jN$, wherein $0 \leq b \leq 1$, $0 \leq c \leq 1$, $0 \leq d \leq 1$, $0 \leq e \leq 1$, $0 \leq f \leq 1$, $0 \leq g \leq 1$, $0 \leq h \leq 1$, $0 \leq i \leq 1$ and $0 \leq j \leq 1$, $b+c+d+e+f+g+h+i+j=1$.

In one embodiment the nitride layer is a nitride of Al and one or more of Zr, Hf, V, Ta, Nb, Si and Cr, preferably a nitride of Al and one or more of Ti and Cr.

25 In one embodiment the nitride layer is a (Ti,Al)N layer of the general formula $Ti_bAl_{1-b}N$, wherein $0 < b < 1$, or $0.1 < b < 0.9$, or $0.2 < b < 0.7$, or $0.3 < b < 0.6$.

In one embodiment the nitride layer is a (Ti,Al,Cr)N layer of the general formula $Ti_bCr_hAl_{1-b-h}N$, wherein $0 < b < 1$, $0 < h < 1$, $0 < b+h < 1$. In one embodiment $0.1 < b < 0.9$ and $0.05 < h < 0.8$, or $0.2 < b < 0.8$ and $0.05 < h < 0.5$.

30 In one embodiment the nitride layer is an (Al,Cr)N layer of the general formula $Cr_hAl_{1-h}N$, wherein $0 < h < 1$. In one embodiment $0.2 < h < 0.8$, or $0.25 < h < 0.75$, or $0.25 < h < 0.35$.

Suitably, in the $(Al_aMe_{1-a})_2O_3$ layer $0.1 \leq a \leq 1$, or $0.25 \leq a \leq 1$, or $0.5 \leq a \leq 1$, or $0.75 \leq a \leq 1$, or $0.25 \leq a \leq 0.9$, or $0.25 \leq a \leq 0.7$.

35 In one embodiment the $(Al_aMe_{1-a})_2O_3$ layer is an $(Al_aCr_{1-a})_2O_3$ layer.

In one embodiment the $(Al_aMe_{1-a})_2O_3$ layer is an Al_2O_3 layer.

The Al_2O_3 layer is suitably of a gamma crystal structure.

The $(\text{Al}_a\text{Me}_{1-a})_2\text{O}_3$ layer is suitably of a gamma crystal structure.

In one embodiment the oxide layer is the uppermost layer of the coating.

In one embodiment the coating has a further layer on top of the oxide layer (A)
5 for wear protection-, decorative- or wear recognition purposes. This uppermost layer has suitably a thickness of 0.1-10 μm and can for example be of nitrides such as TiN, (Ti,Al)N, CrN, HfN, carbides such as TiC, borides such as TiB_2 or oxides (AlMe_2O_3 , ZrO_2 , TiO_2 , V_2O_5) (including metallic interlayers) or multilayers of the forementioned.

The coating is suitably substantially free from droplets of target material on its
10 surface.

In order to improve the adhesion between the nitride layer and the oxide layer a thin (2-200 nm) layer of metallic Al or Al+Me, Me is one or more of Ti, Mg, Ag, Zr, Si, V, Fe, Hf, B and Cr, can be deposited. During the PVD deposition of the oxide layer the metallic layer is partly or fully oxidized. Thus, in one embodiment there is a thin (2-200
15 nm) part of (Al,Me,O) inbetween the nitride layer and the oxide layer, the atomic ratio (Al+Me)/O being equal to or greater than 2/3. The part of (Al,Me,O) can be as a continuous layer or as inclusions of (Al,Me,O).

The substrate of the coated cutting tool can be of any kind common in the field of cutting tools for metal machining. Substrates include cemented carbide, cermet,
20 cBN, ceramics and HSS.

In one embodiment, the substrate is cemented carbide having a composition of 10-14 wt% Co, optionally up to 10 wt% carbides or carbonitrides of one or more metals from groups 4, 5 and 6 in the periodic table of elements, and balance WC.

The metals from groups 4, 5 and 6 in the periodic table of elements are suitably
25 belonging to the group of Ti, Ta, Nb, V, Zr, Cr, W and Mo.

The magnetic coercivity of the cemented carbide body is suitably 15-25 kA/m, or 17-22 kA/m.

For coercivity measurements it is referred to standard DIN IEC 60404-7.

The grain size of the WC, d, in the cemented carbide body is suitably 0.20-0.80
30 μm , or 0.30-0.70 μm , or 0.40-0.60 μm .

The grain size of the WC, d, is determined from the value of magnetic coercivity. The relationship between coercivity and grain size of WC is described, e.g., in Roebuck et al., Measurement Good Practice No. 20, National Physical Laboratory, ISSN 1368-6550, November 1999, Revised February 2009, Section 3.4.3, pages 19-
35 20. For the purposes of this application the grain size of the WC, d, is determined according to formula (8) on page 20 in the above-mentioned literature:

$K=(c_1+d_1W_{Co})+(c_2+d_2W_{Co})/d$. Re-arranging one gets:

$$d = (c_2+d_2W_{Co}) / (K-(c_1+d_1W_{Co})), \text{ wherein}$$

- 5 d = WC grain size of the cemented carbide body, K = coercivity of the cemented carbide body in kA/m, herein measured according to standard DIN IEC 60404-7, W_{Co} = wt% Co in the cemented carbide body, $c_1 = 1.44$, $c_2 = 12.47$, $d_1 = 0.04$, and $d_2 = -0.37$.

The coated cutting tool can be a coated cutting insert, such as a coated cutting insert for turning or a coated cutting insert for milling, or a coated cutting insert for
10 drilling, or a coated cutting insert for threading, or a coated cutting insert for parting and grooving. The coated cutting tool can also be a coated solid drill or endmill. In a preferred embodiment the coated cutting tool is a coated solid drill or coated endmill.

It has now also been provided a method for producing a coated cutting tool comprising a substrate with a coating comprising a nitride layer which is a nitride of at
15 least Ti and Al, and an oxide layer comprising aluminum.

The method comprises depositing a 0.5-5 μm nitride layer which is a nitride of one or more of Zr, Hf, V, Ta, Nb, Si, Cr and Al, onto a substrate followed by depositing a 0.1-5 μm oxide layer being an $(Al_aMe_{1-a})_2O_3$ layer, $0.05 \leq a \leq 1$, Me is one or more of Ti, Mg, Ag, Zr, Si, V, Fe, Hf, B and Cr, the nitride layer and the oxide layer are deposited
20 by a High Power Impulse Magnetron Sputtering (HIPIMS).

In one embodiment the substrate temperature during the magnetron sputtering is from 350 to 600°C, or from 400 to 500°C.

For the deposition of the nitride layer with HIPIMS the DC bias voltage is suitably 20-100 V, or 30-75 V.

25 For the deposition of the nitride layer with HIPIMS the average power density is suitably 20-100 $\text{W}\cdot\text{cm}^{-2}$, or 30-75 $\text{W}\cdot\text{cm}^{-2}$.

The maximum local peak power density during a pulse used in the HIPIMS process in the deposition of the nitride layer is suitably more than 100 $\text{W}\cdot\text{cm}^{-2}$, or more than 500 $\text{W}\cdot\text{cm}^{-2}$, or more than 900 $\text{W}\cdot\text{cm}^{-2}$.

30 The maximum local peak power density during a pulse used in the HIPIMS process in the deposition of the oxide layer is suitably more than 50 $\text{W}\cdot\text{cm}^{-2}$, or more than 100 $\text{W}\cdot\text{cm}^{-2}$, or more than 200 $\text{W}\cdot\text{cm}^{-2}$.

The maximum local peak current density during a pulse used in the HIPIMS process in the deposition of the nitride layer is suitably more than 0.4 $\text{A}\cdot\text{cm}^{-2}$, or more
35 than 0.8 $\text{A}\cdot\text{cm}^{-2}$, or more than 1.2 $\text{A}\cdot\text{cm}^{-2}$.

The maximum local peak current density during a pulse used in the HIPIMS process in the deposition of the oxide layer is suitably more than $0.2 \text{ A}\cdot\text{cm}^{-2}$, or more than $0.4 \text{ A}\cdot\text{cm}^{-2}$, or more than $0.6 \text{ A}\cdot\text{cm}^{-2}$.

For the deposition of the oxide layer with HIPIMS the unipolar bias voltage is
5 suitably 20-400 V, or 50-200 V, or 75-150 V.

For the deposition of the oxide layer with HIPIMS the average power density is suitably $5\text{-}150 \text{ W}\cdot\text{cm}^{-2}$, or $10\text{-}60 \text{ W}\cdot\text{cm}^{-2}$.

The pulse length used in the HIPIMS process in both the deposition of the nitride layer and the deposition of the oxide layer is suitably from $2 \mu\text{s}$ to 200 ms, or
10 from $10 \mu\text{s}$ to 100 ms.

The nitride layer can be represented by the general formula $\text{Ti}_b\text{Zr}_c\text{Hf}_d\text{V}_e\text{Ta}_f\text{Nb}_g\text{Cr}_h\text{Si}_i\text{Al}_j\text{N}$, wherein $0 \leq b \leq 1$, $0 \leq c \leq 1$, $0 \leq d \leq 1$, $0 \leq e \leq 1$, $0 \leq f \leq 1$, $0 \leq g \leq 1$, $0 \leq h \leq 1$, $0 \leq i \leq 1$ and $0 \leq j \leq 1$, $b+c+d+e+f+g+h+i+j=1$.

In one embodiment the nitride layer is a nitride of Al and one or more of Zr, Hf,
15 V, Ta, Nb, Si and Cr, preferably a nitride of Al and one or more of Ti and Cr.

In one embodiment the nitride layer is a (Ti,Al)N layer of the general formula $\text{Ti}_b\text{Al}_{1-b}\text{N}$, wherein $0 < b < 1$, or $0.1 < b < 0.9$, or $0.2 < b < 0.7$, or $0.3 < b < 0.6$.

In one embodiment the nitride layer is a (Ti,Al,Cr)N layer of the general formula $\text{Ti}_b\text{Cr}_h\text{Al}_{1-b-h}\text{N}$, wherein $0 < b < 1$, $0 < h < 1$, $0 < b+h < 1$. In one embodiment $0.1 < b < 0.9$ and
20 $0.05 < h < 0.8$, or $0.2 < b < 0.8$ and $0.05 < h < 0.5$.

In one embodiment the nitride layer is an (Al,Cr)N layer of the general formula $\text{Cr}_h\text{Al}_{1-h}\text{N}$, wherein $0 < h < 1$. In one embodiment $0.2 < h < 0.8$, or $0.25 < h < 0.75$, or $0.25 < h < 0.35$.

Suitably, in the $(\text{Al}_a\text{Me}_{1-a})_2\text{O}_3$ layer $0.1 \leq a \leq 1$, or $0.25 \leq a \leq 1$, or $0.5 \leq a \leq 1$, or
25 $0.75 \leq a \leq 1$, or $0.25 \leq a \leq 0.9$, or $0.25 \leq a \leq 0.7$.

In one embodiment the $(\text{Al}_a\text{Me}_{1-a})_2\text{O}_3$ layer is an $(\text{Al}_a\text{Cr}_{1-a})_2\text{O}_3$ layer.

In one embodiment the $(\text{Al}_a\text{Me}_{1-a})_2\text{O}_3$ layer is an Al_2O_3 layer.

The Al_2O_3 layer is suitably of a gamma crystal structure.

The $(\text{Al}_a\text{Me}_{1-a})_2\text{O}_3$ layer is suitably of a gamma crystal structure.

30 The present invention finally relates to the use of the coated cutting tool herein defined for machining of ISO-S materials

ExamplesExample 1 (invention):

Cemented carbide solid endmill blanks were provided having a composition of
5 12 wt% Co, 0.46 wt% Cr and balance WC.

The grain size d_{WC} , determined from coercivity 19 kA/m, was 0.5 μm .

Sample 1:

A (Ti,Al)N layer was deposited by HIPIMS using sequential power pulses
10 provided according to the description in US 2014/0339917A1. An Oerlikon Balzers S3P
Ingenia equipment was used. The following process parameters/conditions were used:

	Total pressure:	0.61 Pa
	Ar-pressure:	0.43 Pa
	N ₂ -pressure:	0.18 Pa
15	Substrate temperature:	430°C
	Bias voltage:	-40 V DC
	Bias current:	-4.1 A
	Power per Ti40Al60 target:	9.06 kW
	Target diameter:	160 mm
20	Estimated max. local peak power density during pulse:	900 W·cm ⁻²
	Estimated max. local peak current density during pulse:	1.2 A·cm ⁻²
	On-time of pulse:	7.56 ms
25	Pulse frequency:	20 Hz
	Deposition time:	180 minutes

The layer thickness was measured to 2.8 μm on flank face. The hardness of the
deposited (Ti,Al)_xN layer was measured to 3300HV0.015. The reduced E-modulus was
30 measured to 450 GPa.

Further, a very thin layer (2-20 nm) metallic (Al,Cr) (minor amounts Cr due to a
Cr-containing fringe on the Al-target used) was deposited by HIPIMS using sequential
power pulses. The following process parameters/conditions were used:

35	Ar-pressure:	0.6 Pa (= total pressure)
	Substrate temperature:	430°C
	Bias voltage:	100 V unipolar pulsed

	Bias current:	-0.2 A, +0.3 A
	Bias on-time:	10 μ s
	Bias off-time:	10 μ s
5	Power:	5 kW on 3x Al-targets (with Al50Cr50 fringe)
	Target diameter:	160 mm
	Average power density:	8.3 W \cdot cm ⁻²
	On-time of pulse:	50 ms
	Pulse frequency:	6.67 Hz
10	Deposition time:	13 s

Further, an Al₂O₃ layer (with slight amount of Cr) was deposited in the same reactor by HIPIMS using sequential power pulses provided according to the description in US 2014/0339917A1. The following process parameters/conditions were used:

15	Total pressure:	0.72 Pa
	Ar-pressure:	0.6 Pa
	O ₂ -pressure:	0.12 Pa
	Substrate temperature:	430°C
	Bias voltage:	100 V unipolar pulsed
20	Bias current:	-1.2 A, +1.3 A
	Bias-On-time:	10 μ s
	Bias-Off-time:	10 μ s
	Power:	10 kW on 3x Al-targets (with Al50Cr50 fringe)
25	Target diameter:	160 mm
	Estimated max. local peak power density during pulse:	200 W \cdot cm ⁻²
	Estimated max. local peak current density during pulse:	0.6 A \cdot cm ⁻²
30	On-time of pulse:	50 ms
	Pulse frequency:	6.67 Hz
	Deposition time:	140 minutes

The deposited Al₂O₃ layer contained <1 at.% of Cr.

35 The deposited Al₂O₃ layer was determined by XRD to be a gamma-Al₂O₃ layer. The layer thickness was measured to 0.65 μ m. The hardness of the deposited Al₂O₃ layer was measured to 2800HV0.015. The reduced E-modulus was measured to 370 GPa.

Sample 2:

A comparative sample where the same substrate as for Sample 1 has a coating of (Ti,Al)N consisting of a bonding layer next to the substrate of (Ti,Al)N deposited by arc evaporation in an Oerlikon Balzers Innova equipment using two $Ti_{0.50}Al_{0.50}$ targets. The following process parameters/conditions were used:

10 N_2 -pressure: 0.8 Pa
 Substrate temperature: 550°C
 Bias voltage: 70 V
 Deposition time: 4 minutes

15 Then a main layer being a nanolayered (Ti,Al)N having an average composition of $Ti_{0.44}Al_{0.56}N$ was deposited using two $Ti_{0.33}Al_{0.67}$ targets and four $Ti_{0.50}Al_{0.50}$ targets.

N_2 -flow: 1400 sccm
 Substrate temperature: 550°C
 Bias voltage: 60 V
 Deposition time: 80 minutes

20 Finally a decorative layer of (Ti,Al)N was deposited using two $Ti_{0.33}Al_{0.67}$ targets. The following process parameters/conditions were used:

25 N_2 -flow: 1400 sccm
 Substrate temperature: 550°C
 Bias voltage: 60 V
 Deposition time: 5 minutes

30 The surface roughness of the coating itself was measured on individuals of samples 1 and 2 where the surface of the substrates had been polished prior to the deposition of the coating. This was made in order to minimize the influence of the roughness of the substrate to the measured surface roughness value. Surface roughness R_a were measured with a Hommel-Etamic equipment using software Turbo Wave V 7.32. Stylus sampling length 4.8 mm, 0.5 mm/s. (according to DIN EN ISO 11562/ DIN EN ISO 4287). Table 1 shows the results.

35

Table 1.

	R _a (μm)
Sample 1	0.04
Sample 2	0.09

The coated endmills were then tested in a milling operation in a titanium alloy.

- 5 The tool geometry for the solid round endmill was Coromant CoroMill Plura 2S342-1000-100-CMA, diameter 10 mm, 4 flute, corner radius 1 mm. Flute angle of the tool is 42°, one coolant exit per flute. All tools used in this test were from the same production order.
- 10 Work piece material: Ti6Al4V, 175x175x50 mm
Machine: Mori Seiki
Liquid cooling, external nozzles, coolant Blasocut B25 (concentration 9%) through external nozzles
- 15 Test 1:
 $a_p = 2.5$ mm
 $a_e = 2.0$ mm
 $V_c = 100$ m/min (cutting speed in meters per minute)
 $f_z = 0.04$ mm/tooth (feed rate in millimeter per tooth)
- 20 Number of passes = 230
Milling length = 40.25 m
Machining time = 79.03 min

25 Average wear depth at the corner: 0.06 mm, average wear depth at depth of cut (DOC): 0.05 mm. Maximum wear depth at the corner: 0.07 mm, maximum wear depth at DOC: 0.05 mm.

30 Wear of the comparative sample was (after 160 passes equals 28 m or 54.98 min machining time in the same setup as the invention – example): Average wear depth at the corner: 0.05 mm, average wear depth at DOC: 0.23 mm. Maximum wear depth at the corner: 0.10 mm, maximum wear depth at DOC: 0.30 mm (two edges with a wear of 0.30 mm, two edges with a wear of 0.15 mm).

Test 2 (repeated once):

$a_p = 2.5$ mm

$a_e = 1.0$ mm

$V_c = 100$ m/min (cutting speed in meters per minute)

5 $f_z = 0.11$ mm/tooth (feed rate in millimeter per tooth)

Number of passes = 120 for all tools

Milling length = 21 m

Machining time = 11.53 min

10 Average wear depth at the corner: 0.08 mm, average wear depth at DOC: 0.13 mm. Maximum wear depth at the corner: 0.14 mm, maximum wear depth at DOC: 0.23 mm.

Wear of the comparative sample:

15 Average wear depth at the corner: 0.08 mm, average wear depth at DOC: 0.21 mm. Maximum wear depth at the corner: 0.21 mm, maximum wear depth at DOC: 0.50 mm.

After machining the endmills were inspected by SEM at a magnification of 500X for the rake face and 300X for the flank face.

20 It was much less smearing of the Ti-based workpiece material on the exposed (Ti,Al)N at the edge of the cutting tool of the invention (Sample 1) than on the (Ti,Al)N at the edge of the cutting tool of the comparison (Sample 2). This was the case both for the rake and flank faces.

25 Furthermore, It was much less built-up edge on the cutting edge of the cutting tool of the invention (Sample 1) than on the edge of the cutting tool of the comparison (Sample 2). This was the case both for the rake and flank faces.

Claims

1. A coated cutting tool comprising a substrate of cemented carbide, cermet, cBN,
5 ceramics or HSS, with a coating comprising a nitride layer which is a High Power
Impulse Magnetron Sputtering (HIPIMS)-deposited layer of a nitride of one or more of
Ti, Zr, Hf, V, Ta, Nb, Cr, Si and Al, and a HIPIMS-deposited oxide layer being an
(Al_aMe_{1-a})₂O₃ layer, 0.05≤a≤1, wherein Me is one or more of Ti, Mg, Ag, Zr, Si, V, Fe,
Hf, B and Cr, the oxide layer is situated above the nitride layer.
- 10 2. A coated cutting tool according to claim 1, wherein the nitride layer is a (Ti,Al)N
layer of the general formula Ti_bAl_{1-b}N, wherein 0<b<1, or 0.1<b<0.9, or 0.2<b<0.7, or
0.3<b<0.6.
- 15 3. A coated cutting tool according to any one of claims 1 or 2, wherein the (Al_aMe<sub>1-
a</sub>)₂O₃ layer is an (Al_aCr_{1-a})₂O₃ layer.
4. A coated cutting tool according to any one of claims 1-3, wherein the thickness
of the nitride layer is 0.5-5 μm and the thickness of the oxide layer is 0.1-5 μm.
- 20 5. A coated cutting tool according to any one of claims 1-4, wherein in the
(Al_aMe_{1-a})₂O₃ layer 0.1≤a≤1, or 0.25≤a≤1, or 0.5≤a≤1.
6. A coated cutting tool according to any one of claims 1-5, wherein the substrate
25 is cemented carbide.
7. A method for producing a coated cutting tool comprising depositing a 0.1-5 μm
nitride layer which is a nitride of one or more of Ti, Zr, Hf, V, Ta, Nb, Cr, Si and Al, onto
a substrate followed by depositing a 0.1-3 μm oxide layer being an (Al_aMe_{1-a})₂O₃ layer,
30 0.05≤a≤1, Me is one or more of Ti, Mg, Ag, Zr, Si, V, Fe, Hf, B and Cr, the nitride layer
and the oxide layer are deposited by a High Power Impulse Magnetron Sputtering
(HIPIMS) process.
8. A method according to claim 7, wherein the maximum local peak power density
35 used in the HIPIMS process in the deposition of the nitride layer is more than 100
W·cm⁻², or more than 500 W·cm⁻², or more than 900 W·cm⁻².

9. A method according to anyone of claims 7-8, wherein the maximum local peak power density used in the HIPIMS process in the deposition of the oxide layer is more than $50 \text{ W}\cdot\text{cm}^{-2}$, or more than $100 \text{ W}\cdot\text{cm}^{-2}$, or more than $200 \text{ W}\cdot\text{cm}^{-2}$.

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10. A method according to any one of claims 7-9, wherein the maximum local peak current density used in the HIPIMS process in the deposition of the nitride layer is more than $0.4 \text{ A}\cdot\text{cm}^{-2}$, or more than $0.8 \text{ A}\cdot\text{cm}^{-2}$, or more than $1.2 \text{ A}\cdot\text{cm}^{-2}$.

10 11. A method according to any one of claims 7-10, wherein the maximum local peak current density used in the HIPIMS process in the deposition of the oxide layer is more than $0.2 \text{ A}\cdot\text{cm}^{-2}$, or more than $0.4 \text{ A}\cdot\text{cm}^{-2}$, or more than $0.6 \text{ A}\cdot\text{cm}^{-2}$.

12. A method according to any one of claims 7-11, wherein the pulse length used in
15 the HIPIMS process in both the deposition of the nitride layer and the deposition of the oxide layer is from $2 \mu\text{s}$ to 200 ms.

13. A method according to any one of claims 7-12, wherein the substrate
temperature during the HIPIMS process in both the deposition of the nitride layer and
20 the deposition of the oxide layer is from 350 to 600°C .

14. A method according to any one of claims 7-13, wherein the nitride layer is a
(Ti,Al)N layer of the general formula $\text{Ti}_b\text{Al}_{1-b}\text{N}$, wherein $0 < b < 1$, or $0.1 < b < 0.9$, or
 $0.2 < b < 0.7$, or $0.3 < b < 0.6$.

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15. Use of a coated cutting tool according to any one of claims 1-6 for machining of
ISO-S materials.

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/063298

A. CLASSIFICATION OF SUBJECT MATTER
INV. C23C14/06 C23C14/08 C23C14/34 C23C28/04 C23C30/00
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
C23C H01J B23B B22F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

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X	EP 2 392 688 A1 (SANDVIK INTELLECTUAL PROPERTY [SE]) 7 December 2011 (2011-12-07)	1-7,15
Y	paragraph [0029] paragraph [0031] paragraph [0014] paragraph [0019] paragraphs [0030], [0032]	8-13
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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 31 July 2018	Date of mailing of the international search report 08/08/2018
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Kudelka, Stephan
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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/063298

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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Y	LUO Q ET AL: "Hybrid HIPIMS and DC magnetron sputtering deposition of TiN coatings: Deposition rate, structure and tribological properties", SURFACE AND COATINGS TECHNOLOGY, vol. 236, 9 July 2013 (2013-07-09), pages 13-21, XP028788581, ISSN: 0257-8972, DOI: 10.1016/J.SURFCOAT.2013.07.003 paragraph [0002] -----	12
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