PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) **International Patent Classification** 6 : **C23C 14/00, 14/06, 14/54, G02B 5/28**	**A2**	(11) **International Publication Number:** **WO 98/37254** (43) **International Publication Date:** 27 August 1998 (27.08.98)

(21) **International Application Number:** PCT/GB98/00556

(22) **International Filing Date:** 23 February 1998 (23.02.98)

(30) **Priority Data:**
9703616.4 21 February 1997 (21.02.97) GB

(71) **Applicant** *(for all designated States except US)*: THE COURT OF THE UNIVERSITY OF PAISLEY [GB/GB]; University of Paisley, High Street, Paisley PA1 2BE (GB).

(72) **Inventor; and**
(75) **Inventor/Applicant** *(for US only)*: PLACIDO, Frank [GB/GB]; Fairwater, 10 Donaldfield Road, Bridge of Weir, Renfrewshire PA11 3JJ (GB).

(74) **Agent:** MURGITROYD & COMPANY; 373 Scotland Street, Glasgow G5 8QA (GB).

(81) **Designated States:** AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
Without international search report and to be republished upon receipt of that report.

(54) **Title:** THIN FILMS

(57) **Abstract**

The invention provides a thin film comprising successive layers of aluminium oxide, aluminium oxynitride and aluminium nitride, which varies sinusoidally throughout the depth of the film. The film can be used to coat and protect tools with sharp working edges, to provide a stress free thermal protective coating for natural or man–made diamonds, as a light filter and/or as a pigment. It is made by sputtering aluminium using a suitable noble gas in a variable atmosphere of oxygen and nitrogen at room temperature. The film is transparent and has a refractive index which varies between 1.6 to 2.2, again sinusoidally with depth.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania
AM	Armenia
AT	Austria
AU	Australia
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CU	Cuba
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

THIN FILMS

This invention relates to thin films.

Thin film materials have attractive properties for applications in security printing of banknotes, credit cards, telephone cards, smart cards, etc. For example thin films can have highly individual and characteristic reflection properties which are easily recognised by eye, which makes automated recognition a possibility. For security purposes they are not easy to duplicate, requiring expertise and equipment which is outside that commonly available. Thin film pigments can be produced where the colour changes with the viewing angle, making it impossible to duplicate these pigments with normal colour copiers or printers.

For automated recognition it is possible, for example, to produce a film which highly reflects light in one given wavelength range while not reflecting light in a different wavelength range. The reflecting wavelength range is varied by controlling the growth and composition of the film, allowing different, distinguishable films to be produced.

Thin film coatings have been used to protect vulnerable surfaces and to extend the lifetime of sharpedged tools such as drill bits and knifes. A variety of durable materials have been used for this purpose previously, these materials include titanium nitride and tungsten carbide.

A limitation of some other materials with desirable properties such as aluminium oxide and aluminium nitride is the tendency to fail as coatings because of inherent stresses in the thin films which lead to cracking or buckling of the coatings.

Heterogeneous films wherein the refractive index varies with thickness have been a subject of great interest for a number of years.

The ideal material would be one whose refractive index could be varied continuously over a large range although the so-called "digital" technique in which a high-low pair is used to approximate a continuous index range has been used with success.

Previous attempts to produce continuously variable films have used radio frequency (RF) power variation to vary the stoichiometry and/or the density of the growing film, ion-assisted deposition (IAD) and plasma enhanced chemical vapour deposition (PECVD). Of these, PECVD would seem to produce the best quality films.

According to a first aspect of the present invention there is provided a thin film comprising successive layers of aluminium oxide, aluminium oxynitride and aluminium nitride.

Suitably the thin film is stress matched to a substance to which it is applied.

Preferably the thin film is stress free.

More preferably the layers are such that the composition of the film varies generally sinusoidally with depth.

The thin film preferably has a refractive index which varies, preferably sinusoidally between 1.6 and 2.2.

Preferably the refractive index varies between 1.6 and 2.0.

Suitably the thin film is transparent at thicknesses of up to 9 microns.

The invention further provides a method for producing a thin film on a substrate depositing aluminium in an atmosphere of oxygen and/or nitrogen, and varying the oxygen to nitrogen ratio to allow a film of aluminium oxide and/or aluminium nitride and/or aluminium oxynitride to be obtained as necessary. Preferably noble gas is also present in said atmosphere.

Preferably the deposition is performed at room temperature.

The deposition may be by sputtering which may be reactive d.c., reactive low frequency or reactive radio frequency sputtering.

Preferably the low frequency sputtering has a power supply operating in the kilohertz region.

Suitably the aluminium atoms may be removed from the aluminium target by a noble gas plasma.

Optionally reactive sputtering of the aluminium atoms may be achieved solely in the presence of nitrogen and/or oxygen.

The flow rates of the noble gas may be in the range of 0 - 100 sccm.

Suitably the noble gas may be argon.

Suitably the aluminium atoms may react with oxygen and/or nitrogen to form a film or coating on a suitable surface.

Preferably the variation of the oxygen/nitrogen ratio is effected by varying the relative flow rates of the oxygen and nitrogen while maintaining the field strength of the reactive radio frequency.

Suitably the flow rates of the oxygen and nitrogen may be typically in the range of 0 - 10 sccm (standard cubic centimetres per minute). In one example, the thin film produced by the method of the invention consists solely of aluminium nitride.

Preferably the oxygen and nitrogen flow rates are varied generally sinusoidally in anti-phase.

Preferably, also the deposition rate is in the range of 100-800 nm per hour.

Most preferably, the deposition rate is in the range of 100-400 nm per hour.

Further according to the invention there is provided a pigment comprising a thin film as previously defined.

The thin film may be ground to a suitable particle size to achieve the desired spectral properties.

The thin film can be incorporated into a suitable carrier material to form a paint.

Preferably the carrier material is transparent such that the resulting paint retains the same characteristic features of the original films.

In a further aspect, the invention provides a stress matched thin film for coating a diamond surface.

The diamond surface can be of a natural or man-made diamond.

The stress matched thin film can be varied in composition to provide a surface with stress characteristics which match those stress characteristics of another material to which the diamond surface can be attached.

Suitably the thin film can be used to allow diamond surfaces to be attached to tools.

Preferably the diamond surface can be coated with a thin film which confers thermal protection to the diamond.

In another aspect, the invention provides a filter comprising a thin film as previously defined wherein the filter has high transmission except for a narrow region centred on wavelength λ_0.

Suitably the filter may be used as or in laser goggles, laser rejection filters, laser mirrors, head-up displays or any other suitable application.

Still further, the invention provides the use of a thin film as previously defined to coat and protect vulnerable surfaces from chemical attack and/or to extend the lifetime of tools, for example, tools with sharp working edges.

The surfaces may include metals, dielectrics, semiconductors and plastics.

Optionally, once the surfaces have been coated with a thin film as previously described, the thin film can be used to allow an additional coating of diamond to be applied to the surface.

The invention will now be further described, without limitation, by reference to the accompanying drawings, wherein:

Fig 1 is a graph that illustrates how transmission varies as λ_0 varies with the number of deposition cycles.

Fig 2 is a graph that illustrates both the calculated and the measured transmission of the films.

Figs 3 (a), (b) and (c) are spectra which illustrate depth profiling of a thin film using X-ray Photon Spectroscopy (XPS) of O 1s, N 1s and Al 2p binding energies.

Figure 1 shows how the transmission varies as λ_0 varies with the number of cycles deposited for the following parameters, which are in a range appropriate to the aluminium oxynitride films.

Table 1

n_{mean}	n_{range}	λ_o (nm)	t_o (nm)
1.78	0.36	392	110

The calculations for Figure 1 have been performed for a coating on a finite thickness glass substrate immersed in air; the phase of the sine wave is $\phi = 0$. It can be seen that optical densities of 4 (which seems to be a benchmark figure) can be obtained for the above film parameters with 35 deposited cycles, corresponding to a film thickness of 3.85μm.

Figure 2 shows the experimental realisation (full line) of such a filter on glass. After measurement of the transmission the films are broken and the thickness measured on a Hitachi S4100 field emission scanning electron microscope (SEM).

The dotted line in Fig. 2 is calculated spectrum, using the measured cycle thickness and the measured λ_o to calculate n_{mean} from Equn.2 (see Example 3) and adjusting n_{range} for a good fit to the spectral width. The calculation takes into account the glass absorption, but assumes the oxynitride films to be dispersion free. The fit to the side lobes is very sensitive to the assumed starting phase of the sine wave, but is also sensitive to the end layer at the film-air boundary (the end phase of the sine wave in a sense). The spectrum in Fig.2 has 35.4 cycles and ϕ has been adjusted for a good fit to the sidelobes.

Similar filters have been made with λ_o ranging from 300

- 1100 nm and with up to 70 deposited cycles. The centre wavelength is predictable and reproducible when the deposition parameters (target-substrate distance, RF power, gas flow rates, chamber pressure) are unchanged, being dependent only on the deposition time for one cycle. The visual quality of the deposition films is generally very good.

Figure 3 shows that these films are varying continuously in composition and hence in refractive index since alternating layers of aluminium oxide and aluminium nitride with thicknesses close to quarter waves can show similar optical performance. X-ray Photon Spectroscopy (XPS) shows that the oxygen 1s and nitrogen 1s peaks vary sinusoidally and in antiphase with depth from the surface. The aluminium 2p peak, in contrast, is of constant height but varies in energy with depth. This is consistent with the composition of the film varying continuously from aluminium oxide to aluminium nitride. The observed Al 2p shift varies by around 2.9 eV. The aluminium peak is a single peak which varies in position rather than two peaks with varying heights which supports the conclusion that aluminium oxynitrides are continuously variable compounds rather than a mixture of phases of aluminium oxide and aluminium nitride.

This invention relates to the growth of aluminium oxynitride films where the composition is varied continuously from Al_2O_3 to AlN through intermediate compositions AlO_xN_y. This material has a number of highly desirable properties being hard, wear-resistant, adhering strongly to a variety of substrates, transparent to around 9 microns with low absorption, resistant to chemical attack and offers a potential refractive index range of 1.6 to over 2.2.

Additionally, this invention provides for high quality rugate filters, pigments and durable, chemical resistant coatings in which the refractive index varies sinusoidally with thickness.

Example 1

Aluminium Oxynitride Films

To produce aluminium oxynitride films, a sputtering chamber of suitable size containing a magnetron and a target of aluminium, typically a disk of diameter 200 mm, is loaded with the substrate or substrates onto which the film is to be deposited. We have demonstrated that stress-free coatings of hard, wear-resistant, adherent coatings can be deposited on a wide variety of surfaces including metals, dielectrics, semiconductors and plastics by co-depositing aluminium oxide and aluminium nitride whereby inherent stresses are cancelled. This can be done as sequential layers of aluminium oxide and aluminium nitride or as layer of layers of aluminium oxynitride.

A removable shutter can be positioned between the substrates and the target and/or a means for moving the substrates into and out of the sputtering position is also commonly used.

The chamber is evacuated by suitable vacuum pumps, preferably to a residual vacuum of the order of 10^{-7} torr. The chamber is then filled with a noble gas, typically argon, to a pressure which is typically in the range of 1 - 10 millitorr.

A plasma discharge is created by means of a radio-frequency power supply, typically 1 kilowatt in power, for a 200 mm diameter aluminium target. After some time, typically 30 minutes with the shutter obscuring the substrates or having moved the substrates out of the sputtering position, the surface of the target will be conditioned by the plasma and suitable amounts of the reactive gases, oxygen and nitrogen can be added to the noble gas to commence reactive sputtering.

The desired amounts of noble gas, oxygen and nitrogen can be controlled by commonly available mass-flow controllers with mass flows of noble gas, of oxygen and of nitrogen in the range of 0 - 10 sccm (standard cubic centimetres per minute). The shutter can be opened or the substrates then moved into the sputtering position for the time necessary to produce the required thickness of deposit. A typical system as described can produce film deposition rates in the region of 150 - 800 nm/hr (dependent of film composition and target to substrate distance). Higher deposition rates can be achieved using reactive d.c. sputtering or preferably "low-frequency" sputtering whereby a power supply operating at a frequency in the kilohertz region is used to reduce the charging effects encountered with d.c. power supplies.

Example 2

Pigments

Pigments can be produced from thin films by depositing onto and subsequently removing the film from, a suitable surface or substrate. The film can then be ground down to produce a pigment which is long lasting, chemically resistant and can be incorporated into a suitable host to form paints which retain the same characteristic features of the original films which can then be applied to surfaces in a variety of ways.

The colour of pigments manufactured from such films varies with the viewing angle and cannot be reproduced by a photocopier or colour printer.

For this type of application the films may be easily removed and recovered if they are deposited onto substrates or surfaces which are flexible or which can be dissolved in a suitable solvent.

Example 3

Diamond Surfaces

It is not possible to form a diamond layer on some materials. For example, carbon diffuses into hot iron and steel to form iron carbide. In order to obviate this problem, a coating of a suitable material may be layed down onto the steel or iron, for instance, before laying down the diamond. Or alternatively, a thin film of material may be layed down onto a diamond surface first.

A thin film of aluminium oxynitride and/or oxide and/or nitride can be deposited by the technique described using the technique described herein. The stress properties of the film can be modified to match those of the diamond surface so that the film forms a coherent layer on the diamond surface. The composition of the film can then be altered so that the stress properties of the film match those of another material which is to be stuck to the diamond surface via the thin film of aluminium oxynitride and/or oxide and/or nitride.

This technique can be used for example in the manufacture of tools with diamond components where there are significant difficulties in depositing or attaching diamond films onto certain materials. For instance: in the manufacture of diamond tipped drill-bits, grinding and polishing tools. The tool can be treated initially with a thin film of aluminium oxynitride and/or oxide and/or nitride. After this stage is completed the treated tool can be coated with an additional layer of diamond, grown by standard techniques.

Further applications include providing a thermally stable coating for diamond windows for use in optical, IR or UV sensors.

Example 4

Rugate Filters

Rugate filters have a spectral response similar to that of a rejection filter: having high transmission everywhere except a narrow region centred on wavelength, λ_o. The refractive index variation is generally given by

Equn. (1) $$n(z) = n_{mean} + \frac{n_{range}}{2} \sin \left(\frac{4\pi n_{mean} Z}{\lambda_o} + \phi\right)$$

where n_{mean} is the average refractive index, n_{range} is the refractive index range and the geometrical thickness of one sinusoidal cycle, t_o, is

Equn. (2) $$t_o = \frac{\lambda_o}{2n_{mean}}$$

leads to a rejection filter centred on λ_o and with a bandwidth of

Equn. (3) $$\Delta \lambda = 2\lambda_o \left|\frac{n_{range}}{n_{mean}}\right|$$

The phase factor ϕ in Equn.(1) is the optical density at λ_o is important in determining the magnitudes and positions of the sidebands which are observed with this type of filter·

Equn. 2 shows that the centre wavelength is varied by changing the physical thickness of one cycle and Equn 3 shows that the bandwidth can be varied by changing the refractive index range of the sinusoid. In addition the optical density at λ_o is dependent on the number of cycles deposited.

Such filters have application in laser goggles for protection of humans and laser rejection filters for instruments, as general purpose laser mirrors, and in head-up displays. They may also be used instead of the holographic filters in the new generations of compact Raman spectrometers.

The foregoing description of embodiments of the present invention is illustrative of specific embodiments only and is not intended to be limiting. It is to be understood that additional embodiments which may be perceived by those skilled in the art are considered to be within the scope of the present invention.
/u/mur/specs18/p18104-

REFERENCES

1 R Jacobson, "Optical properties of a class of inhomogeneous thin films", Optica Acta 10, 309-323, (1963).

2 E Delano, "Fourier synthesis of multilayer filters", J Opt. Soc. Am. 57, 1529-1533, (1967).

3 J A Dobrowolski and D Lowe. "Optical thin film synthesis program based on the use of Fourier transforms", Appl. Opt. 17, 3039-3050, (1978).

4 W H Southwell, "Spectra response calculations of rugate filters using coupled-wave theory", J Opt. Soc. Am. A5, 1558-1564, (1988).

5 B G Bovard, "Derivation of a matrix describing a rugate dielectric thin film", Appl. Opt. 27, 1998-2005, (1988).

6 R R Wiley, "Rugate Broadbank antireflection coating design", SPIE 1168-26, San Diego, (1989)

7 P G Verly, J A Dobrowolski, W J Wild, and R L Burton, "Synthesis of high rejection filters with the Fourier transform method", Appl. Opt. 28, 2864-2867, (1989).

8 R R Wiley, "Basic nature and properties of inhomogeneous antireflection coatings" in *Inhomogeneous and Quasi-inhomogeneous Optical Coatings*, Jerzy A Dobrowolski, Pierre G Verly, Editors, Proc SPIE 2046, 69-77, (1993).

9 A K Tikhonravov, "Mathematical aspects of the

synthesis of *Inhomogeneous and Quasi-inhomogeneous Optical Coatings*, Jerzy A Dobrowolski, Pierre G Verly, Editors, Proc SPIE 2046, 18-29, (1993).

10 J A Dobrowolski and A V Tikonravov, "Series of optimal and near-optimal solutions to an antireflection problem", in *Inhomogeneous and Quasi-inhomogeneous Optical Coatings*, Jerzy A Dobrowolski, Pierre G Verly, Editors, Proc SPIE 2046, 62-68, (1993).

11 C K Hwangbo, L J Lingg, J P Lehan, H A MacLeod and F Suits, "Reactive ion assisted deposition of aluminium oxynitride thin films", Appl Opt. 28, 2779-2784, (1989).

12 M F Oullette, R V Lang, K L Yan, R W Bertram and R S Owles, "Experimental studies of inhomogeneous coatings of optical applications", J Vac Sci, Technol. A9, 1188-1192. (1991).

13 A F Jankowski, L R Schrawyer and P L Perry, "Reactive sputtering of molybdenum-oxide gradient-index filters", J Vac. Sci. Technol. A9, 1184-1187, (1991).

14 S Lim, J H Ryu, J F Wager and T K Plant, "Rugate filters grown by plasma-enhanced chemical vapour deposition", Thin Solid Films, 245, 141-145, (1993).

15 J N Kidder, J S Kuo, A Ludviksson, T P Pearsall, J W Rogers, J M Grant, L R Allen and S T Hsu, "Deposition of AIN at lower temperatures by atmospheric metalorganic chemical vapour deposition using dimethlethylamine alane and ammonia", J Vac. Sci. Technol. A13, 711-715, (1995).

16 Experimental techniques centre (ETC), Brunel University, Uxbridge, Middlesex UB8 3PH, England.

CLAIMS

1. A thin film comprising successive layers of aluminium oxide, aluminium oxynitride and aluminium nitride.

2. A thin film as claimed in Claim 1, which is stress matched to a substance to which it is applied so as to be stress-free.

3. A thin film as claimed in Claims 1 and 2, the layers of which are such that the composition of the film varies sinusoidally with depth.

4. A thin film as claimed in Claims 1, 2 and 3, which has a refractive index that varies sinusoidally between 1.6 and 2.2.

5. A thin film as claimed in any of the preceding claims, which is transparent at thicknesses of up to 9 microns.

6. A method for depositing a thin film as claimed in claims 1 to 5, which comprises depositing aluminium in an atmosphere of oxygen and/or nitrogen, and varying the oxygen to nitrogen ratio to allow a film of aluminium oxide and/or nitride and/or aluminium oxynitride to be obtained as necessary.

7. A method as claimed in Claim 6 wherein the deposition of aluminium occurs at room temperature.

8. A method as claimed in Claims 6 and 7 wherein the deposition occurs by sputtering, the type of sputtering chosen from the group consisting of reactive d.c., reactive low frequency and reactive radio frequency sputtering.

9. A method as claimed in Claims 6, 7 and 8 wherein the low frequency sputtering has a power supply operating in the kilohertz region.

10. A method as claimed in Claims 6 to 9 wherein the aluminium atoms are removed from the target by a noble gas plasma, flowing at between 0-100 sccm.

11. A method as claimed in Claims 6 to 10 wherein the aluminium atoms are removed from the target solely in the presence of nitrogen and/or oxygen.

12. A method as claimed in Claims 6 to 11, wherein the noble gas is argon.

13. A method as claimed in Claims 6 to 12 wherein the aluminium atoms react with oxygen and/or nitrogen to form a thin film on a suitable surface.

14. A method as claimed in Claims 6 to 13 wherein the flow rates of the argon, oxygen and nitrogen may be varied sinusoidally in anti-phase in the range 0-10 sccm.

15. A method as claimed in Claims 6 to 14 wherein the rate of deposition is in the range 100-800 nm per hour.

16. A method as claimed in Claims 6 to 15 wherein the rate of deposition is in the range 100-400 nm per hour.

17. A thin film as claimed in Claims 1-5 which is used as a pigment.

18. A thin film as claimed in Claims 1 to 5 and 17 wherein the thin film is ground to a suitable particle size to achieve the desired spectral properties.

19. A thin film as claimed in Claims 1 to 5 and 17 and 18 wherein the thin film is incorporated into a transparent carrier material to make a paint.

20. A thin film as claimed in Claims 1 to 5 and 17 to 19 wherein the thin film is used to provide a stress matched film to natural or man-made diamond.

21. A thin film as claimed in Claims 1 to 5 and 17 to 20 wherein the thin film is stress matched to provide a surface with stress characteristics which match those stress characteristics of another material to which the diamond surface can be attached.

22. A thin film as claimed in Claims 1 to 5 and 17 to 21 wherein the thin film is used to allow diamond surface to be attached to tools.

23. A thin film as claimed in Claims 1 to 5 and 17 to 22 wherein the thin film confers thermal protection to the diamond surface.

24. A filter comprising a thin film as claimed in Claims 1 to 5 and 17 to 23 wherein the filter has a high transmission except for a narrow region centred on a wavelength .

25. A filter as claimed in Claim 24 wherein the filter is used in laser goggles, laser rejection filters, laser mirrors, head up displays and any other suitable application.

26. A thin film as claimed in Claims 1 to 5 and 17 to 23 wherein the thin film is used to coat and protect vulnerable surfaces from chemical attack and to extend the lifetime of tools with sharp working edges.

27. A thin film as claimed in Claims 1 to 5, 17 to 23 and 26 wherein the thin film is used to coat and protect vulnerable surfaces chosen from the group consisting of metals, dielectrics, semiconductors and plastics.

28. A thin film as claimed in Claims 1 to 5, 17 to 23, 26 and 27 wherein the thin film used to coat and protect vulnerable surfaces chosen from the group consisting of metals, dielectrics, semiconductors and plastics is used to allow an additional coating of a diamond to be applied to the surfaces.

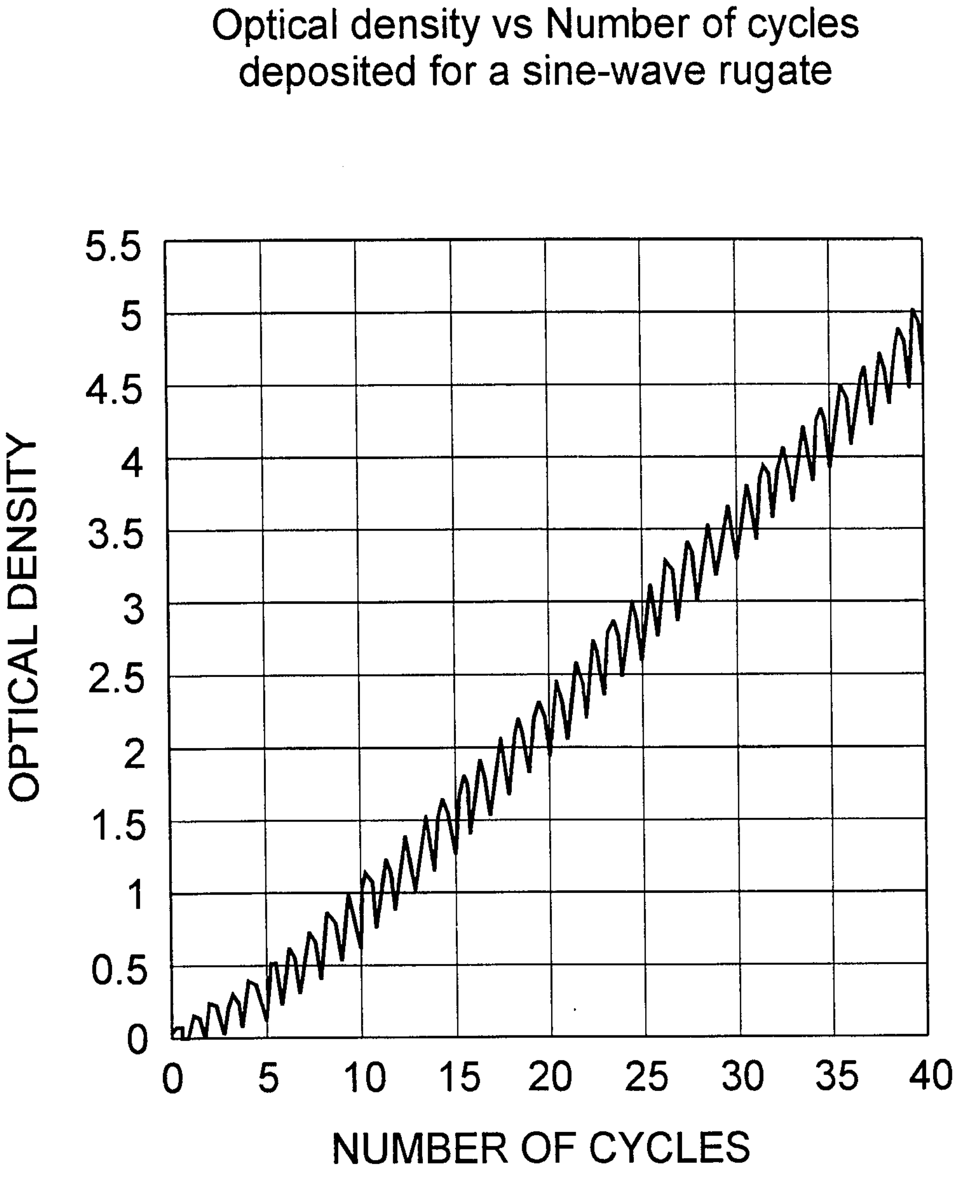
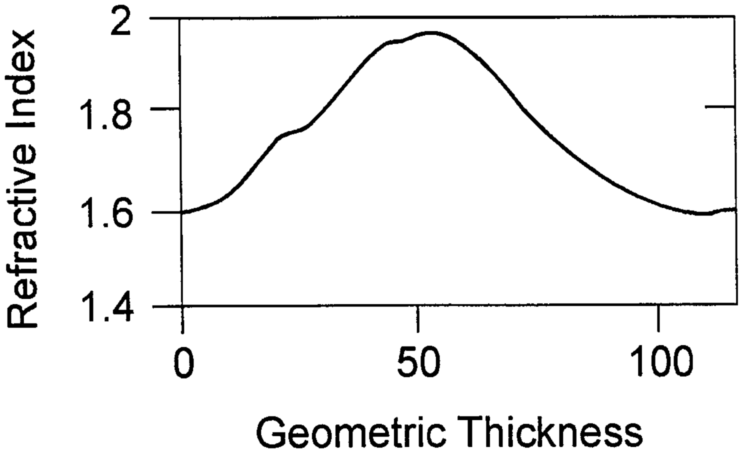
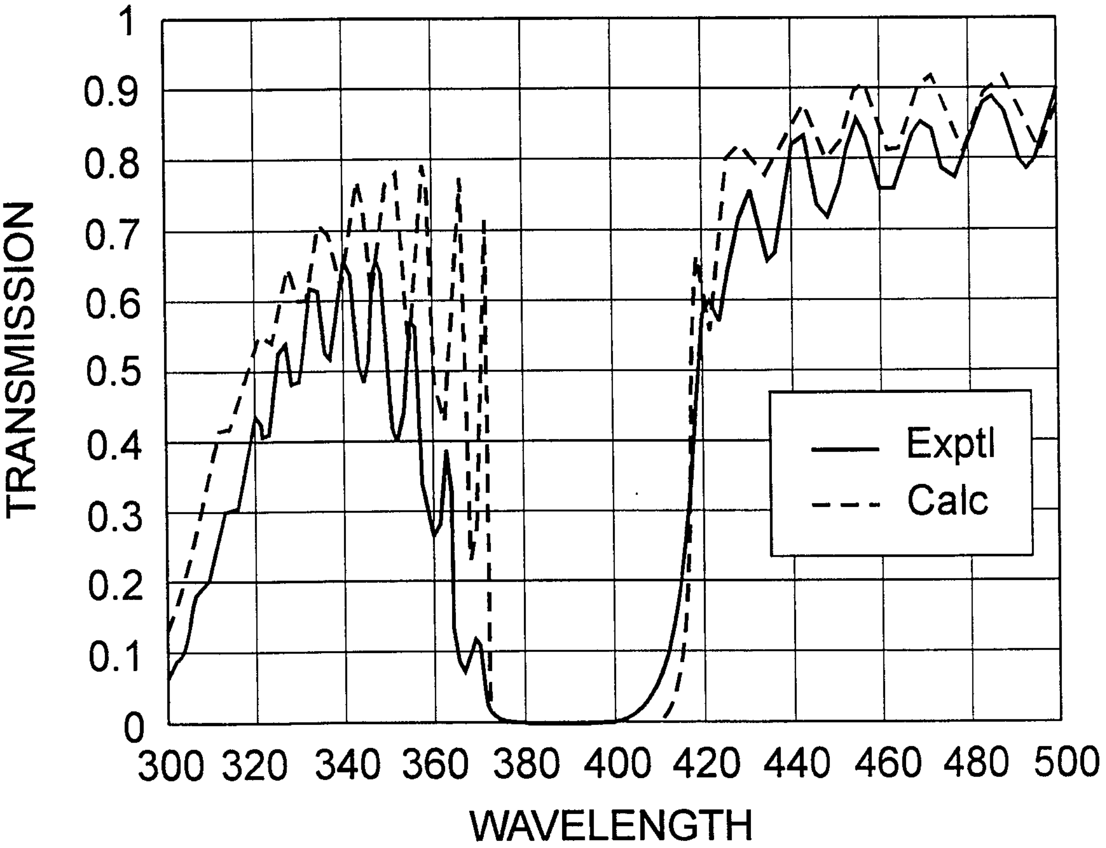

Optical density vs Number of cycles
deposited for a sine-wave rugate
OPTICAL DENSITY
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
NUMBER OF CYCLES

Fig. 1





Transmission of an experimental rugate
on glass with calculated spectrum

Fig. 2

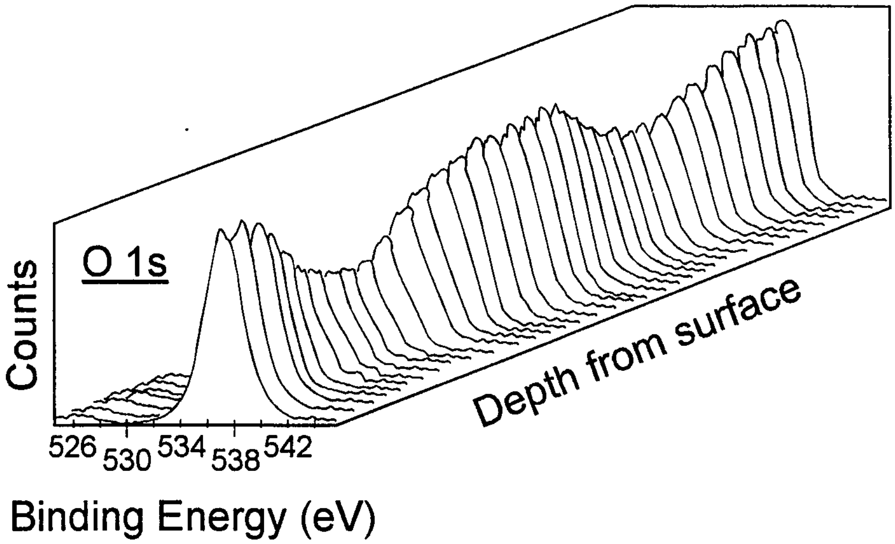


Fig. 3a

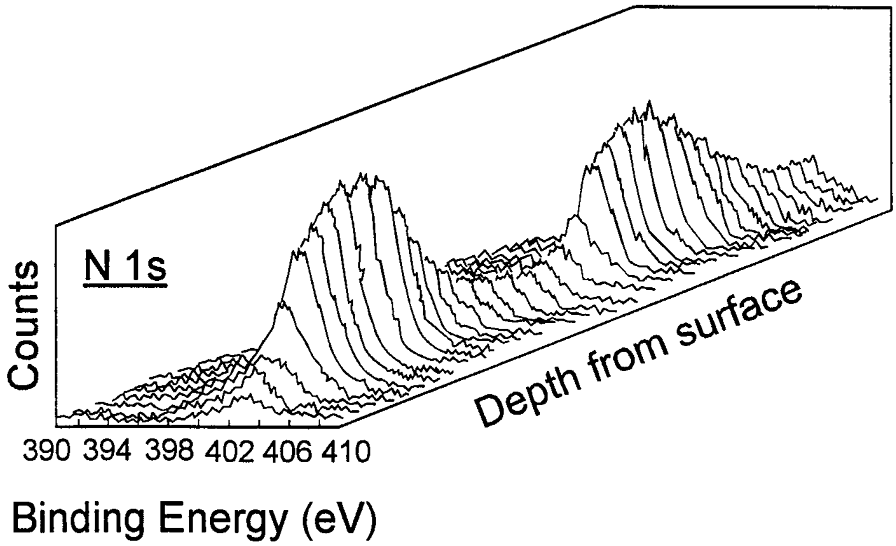


Fig. 3b

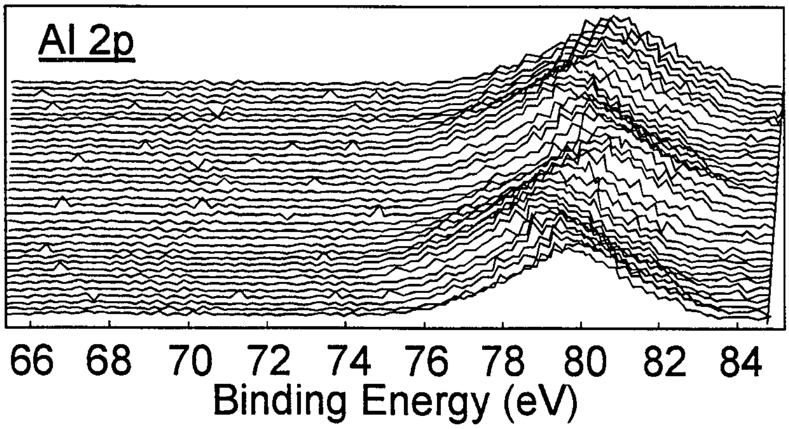


Fig. 3c

Depth profiling XPS:
Oxygen, nitrogen and aluminium