Plasma etching optimization on complex geometries made possible by PLATIT's 3D etch indicator

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Wear-resistant hard coatings and cutting-edge preparation took over key roles in the optimizations of precision tools. In addition to the correct selection of the micro tool geometry, the hard coating must also be adapted to suit the application [1]. The best protective hard coating system could not show its full potential without fulfilling the basic requirement: sufficient adhesion to the substrate material. Prior to the thin film deposition, the substrate material must be free from any impurities on the atomic scale. This can be achieved in high-vacuum PVD systems with glow discharge techniques igniting a plasma directly on the substrates and carousel at several hundred volts prior to the PVD and/or PECVD process [2,3,4].

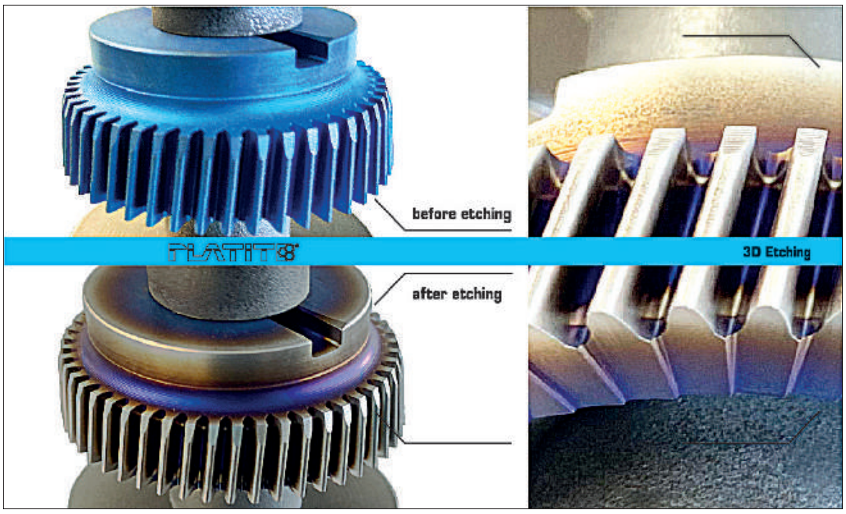

figure 2
The pinion cutter covered with homogenous interference color layer prior to the etching process and the resulting change of the color after the etching; the changed colors provide the 3D map of the etching efficiency

Several inventions were proposed to suppress the inhomogeneous material removal rate typical for glow discharge methods [5, 6, 7]. However, current methods for estimating the etching rate are insufficient to evaluation the resulting homogeneity, with limited applicability only on planar substrates[6]. So far, it has not been possible to reliably evaluate the etching rate for most critical substrate surfaces such as a cutting edge of the cutting tools.

With this article we would like to introduce our patented 3D plasma etch indicator, which is considered as a breakthrough in plasma etching profile measurement. This new approach provides a 3D visual profile of the plasma etching efficiency over several tens of centimeters of the surface of any shape with the ability to tailor a dedicated etch profile to industrial parts of interest.

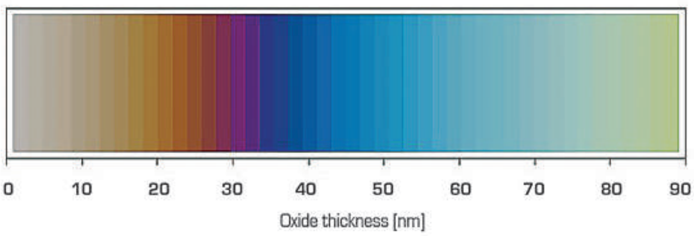

figure 1
Scale of interference colors of a thin TiO_2 layer with its corresponding thickness, see literature [8]

To obtain such a 3D etch profile, the studied samples (e.g., cutting tools) were covered with thin films reflecting homogenously a single interference color (e.g., blue). These samples were then placed into the coating chamber and the plasma etching procedure was carried out for a defined time. After plasma etching, the thin inference layer on the sample surface decreased unevenly in terms of thickness. Since thin film interference color corresponds directly to its thickness, the resulting color at any point of the surface provides the information on the etching efficiency at that particular point with a resolution of 5 to 10 nanometer.

Figure 1 shows a scale of interference colors of a thin TiO_2 layer with its corresponding thickness reprinted from the literature[8]. *Figure 2* illustrates the usage of the 3D etch indicator on the pinion cutter. With help of the scale in *figure 1*, the color change after etching reveals the reduction of the layer's thickness and thus the etching efficiency on the 3D profile of the substrate.

When using the 3D plasma etch indicator, we found important information regarding the character of glow discharge processes, which are finally being used to optimize the coating adhesion:

1.
It was discovered that the measurement of the etch rate on the flat test pieces is not relevant for the estimation of the etch efficiency on industrial samples with 3D geometries.

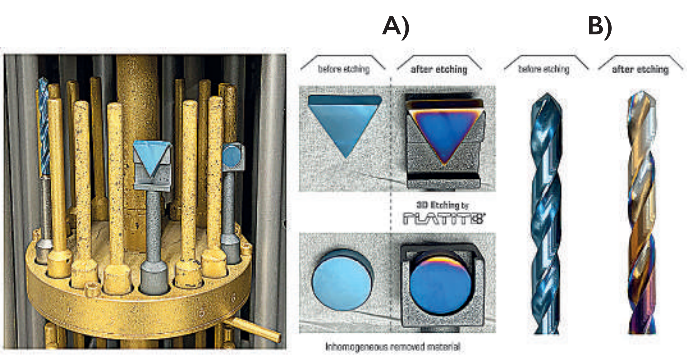

figure 3
Joint loading of one drill and two samples of different shapes
A) left, *two samples of different shapes coated with homogenous interference layer;* right, *samples of the same shape (and originally the same coating) after the etching process*
B) *drill before and after the etching process*

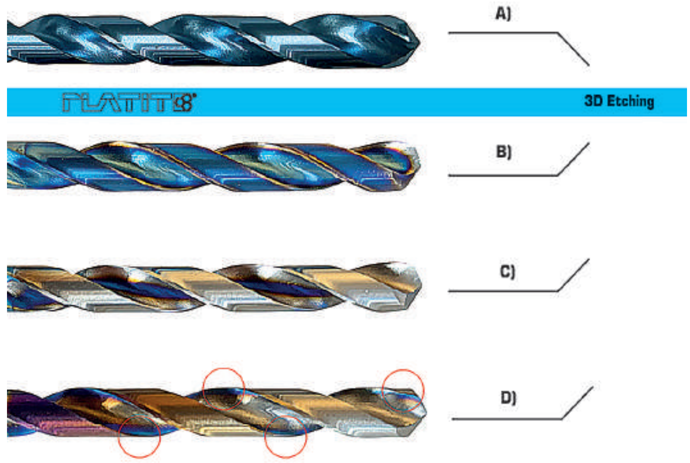

figure 4
Three tools coated with a homogenous light blue TiO_2 56 ± 5 nm thick layer and subsequently etched for 10 min; each tool was etched separately in an argon discharge of three different parameters

Figure 3 shows on the left the joint loading of one drill, one triangle shaped test piece and one round shaped test piece. All three samples were coated with homogenous light blue layer and underwent together the same plasma etching procedure.

Figure 3A) on the left shows the homogenous 56 ± 5 nm thick light blue color layer (see the scale in *figure 1)* on two different test samples. The right side of the figures shows the samples after the etching process. While the dark blue color in the center of the samples corresponds to the thickness of 38 ± 5 nm, the edges of the samples which were exposed to the plasma were etched completely.

Figure 3B) shows the condition of the drill before and after the etching procedure. This tool was etched inhomogeneously. In addition to the clear material removal gradient from top to bottom, we can also notice the residual blue color on the cutting edge, which shows that this crucial part of the tool was not etched sufficiently.

By comparing the etch profile on the samples and on the drill surface, we can conclude that flat test pieces are not able to provide relevant information on the etch efficiency of complex 3D samples. Therefore, the mechanical measurement of the etch profile of partially covered flat samples cannot be sufficient and must be replaced by, e.g., our 3D plasma etch indicator.

2.
We found a way to measure and visualize that different discharge parameters result in very different distributions of plasma etching.

While methods using the flat test pieces were able to compare the etching efficiency of different discharge parameters on one dimensional scale, we found out that the actual 3D character of the etch profile differs significantly for different discharge parameters. *Figure 4* shows an example of the three tools coated with a homogenous light blue 56 ± 5 nm thick layer and subsequently etched for 10 min. Each tool was etched separately under different Ar plasma etching conditions, which we refer to as B), C) and D). *Figure 4A)* shows one tool prior the 10 min etching.

The effect of etching with parameters B) is shown in *figure 4B).* We can see that the interference layer was completely removed on the cutting edges, however, more than 60 % of the interference layer remains in the flute and on the drill land. Such a discharge can sufficiently etch sharp edges, but it is very ineffective on a flat surface.

Figure 4C) shows more effective etching on the land, but about 50 % of the interference layer remains in the flute.

The etching with parameters D) shown in *figure 4D)* shows a very different etching profile.

Unlike the previous examples, we see the inhomogeneity of etching from top to bottom. In addition, we see a very different etch profile when looking at the flute and the cutting edge. While the flute is etched efficiently, we notice a blue residue on the cutting edge *(see the red circles).* This shows that while we can successfully clean the flute at these parameters, the most important part – the cutting edge – remains almost undertreated.

3.
Loading dependency of the material removal rate by plasma etching.

Our 3D etch indicator showed a significant dependency of the etching efficiency on the loading of the tools. While the etch indicator on Ø 6 mm drills placed in a standard shank tool holder showed a relatively high etching efficiency within standard etching processes, micro tools placed in a micro tool holder showed barely any effect within the identical etching process. This might be seen as counter-intuitive because we might expect that micro tools required milder plasma etching than the Ø 6 mm shank tools.

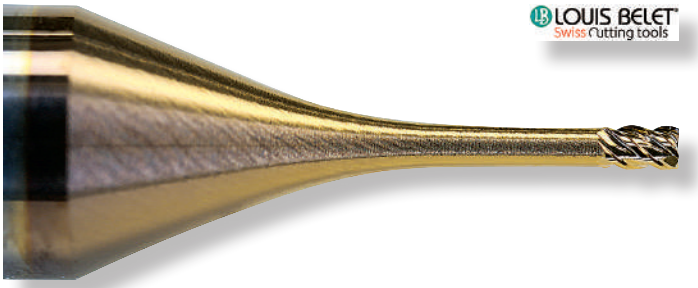

figure 5
Ø 0.5 mm end mill
source Louis Bélet

This information has significantly helped the development of a coating process, in particular, for micro tools. A TiSi-based coating was deposited on cemented carbide Ø 0.5 mm end mill as seen in the *figure 5* and tested within wet machining of titanium alloy at a cutting speed 50 m/min. The micro tool cutting tests were carried out at *Louis Bélet*. The burr heights were measured at regular distances depending on the machining length.

The graph in the *figure 6* shows the result of a dedicated etching optimization, indicating a much lower burr height for the micro tool coating with optimized etching compared to the standard plasma etching generally used for Ø 6 mm shank tools. While conventional optimization of plasma etching required feedback from cutting tests for each set of parameters, with the 3D etch indicator, feedback was visible to the naked eye immediately after the plasma etch test.

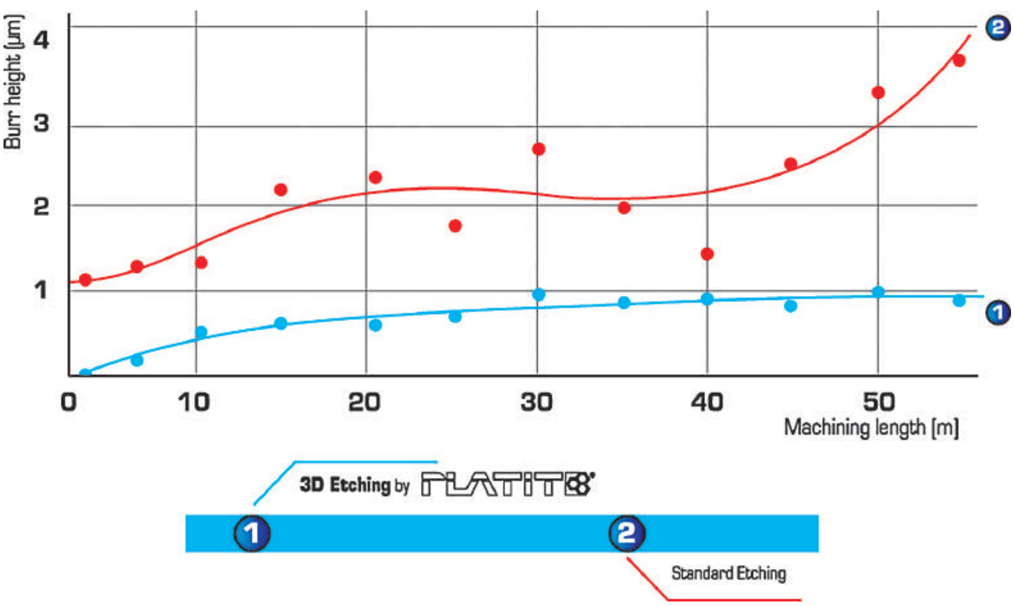

figure 6
Development of burr height as a function of milling length
source Louis Bélet

As a result, the presented 3D plasma etch indicator provides a tool for selecting the right combination of etch parameters and provides dedicated etching processes adapted to the geometries to be coated. This could have never been verified and adjusted across the PVD industry, even though the community is aware that the etching process for shank tools should be different than a gear cutting tool or a segmented die. In this way, 3D etch profiling can be used to ensure that the selected etching strategy leads to 100 % treatment of the sample surface with complex 3D geometry.

Acknowledgement

We would like to thank *Louis Bélet* for providing us with the results of the cutting tests.

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