InkCal™ Software for Feature Size Accuracy

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Introduction

InkCal is a tool available within the InkCAD™ software environment for accurately calculating the diffusion constant (C, $\mu m^2/s$) of various inks. InkCal has been optimized to work on NanoInk's NSCRIPTOR™ DPN® System, but the concepts involved are general and pertain to most DPN patterning. In simple terms, InkCal quantifies the rate of ink diffusion (i.e., how fast the ink is spreading). This in turn gives the user accurate feature size control in the desired pattern. In this way, intricate patterns of high definition can be demonstrated with inks whose diffusion behavior is otherwise unknown.

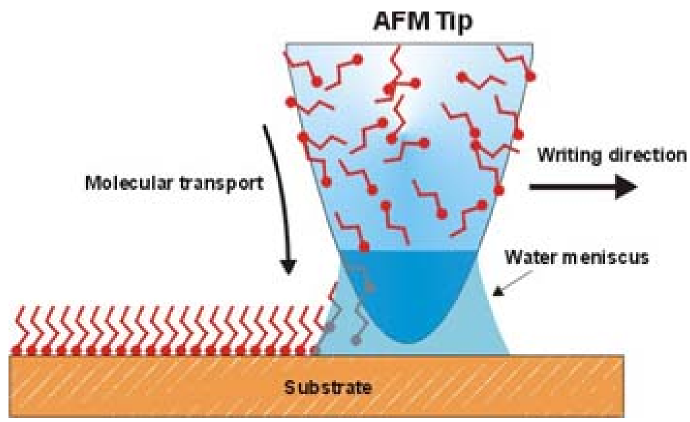

Fig. 1: Schematic representation of the DPN method

In the DPN method, ink is deposited by the pen tip as it moves across the surface of interest, as shown in Fig. 1. There are mainly two types of ink deposition modes: diffusive and stacking. In diffusion mode an ink generally spreads from the tip source, and resulting feature sizes exhibit a definite dependence on dwell time and/or tip speed. In the stacking mode, an ink's interaction with its own molecules is stronger than the ink molecule-substrate interaction. Rather than spreading it stacks up in layers. Stacking is more common for inks which are physisorbed to the substrate rather than chemisorbed.

Additionally, in both diffusive and stacking patterning there are two types of deposition: static and dynamic. Static occurs when the tip is stationary with respect to the substrate (i.e., patterning dots), and the ink is forced to flow outward over its own molecules to find fresh attachment sites on the substrate. Dynamic occurs with a moving tip (i.e., patterning lines), where the ink at the leading edge of the tip is always seeing fresh substrate. As one might expect, these differing processes imply slightly different diffusion constants between dots and lines.

Software Application

The InkCal routine incorporates a variety of diffusion models that correspond to the above concepts, all within an easy to use wizard. The wizard guides the user through the process of ink calibration, which consists of four stepwise Windows™-software frames: design, image, measure, and analyze.

The design portion is seen in Fig. 2a. The user can choose dots, lines, or both, and control lithography parameters such as dwell time and tip speed. "GO" performs the lithography; when lithography is completed, the wizard initiates InkFinder™ to image the InkCal pattern.

Once the desired image has been acquired, the wizard imports the image to the InkCal measurement window seen in Fig. 2b. Simple cursor tools facilitate easy measurement of both line width and dot area.

Following measurement is the analysis window, which plots the relationship between time and DPN feature size (seen in Figs. 2c and d). At this point, the user can select the appropriate diffusion model (i.e., linear or 2nd order polynomial), or they can modify the curve fit with manual intervention. The diffusion constant is taken as the calculated slope of the line; this diffusion constant is then propagated throughout the user's InkCAD pattern designs, and the software uses this knowledge of the ink's behavior to adjust dwell times and tip speeds to achieve the desired dot diameters or line widths. At this point, the user can save the results of the ink calibration into an ink database, both for future reference and to apply the calibration to any new or existing InkCAD patterns.

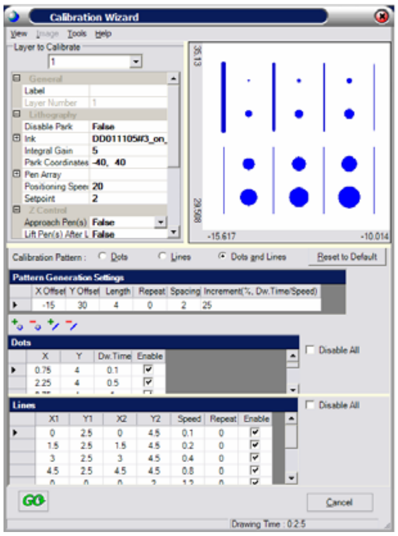

Fig. 2a – InkCal design window

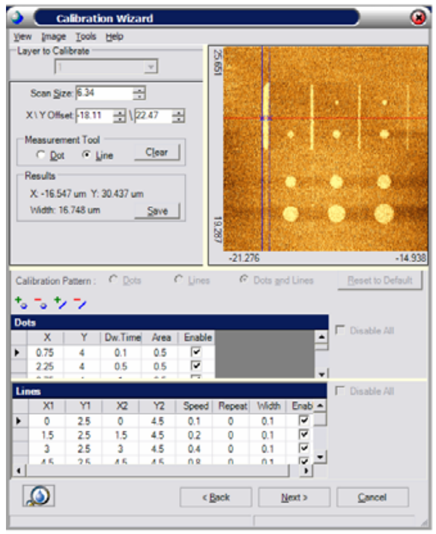

Fig. 2b – InkCal measurement window

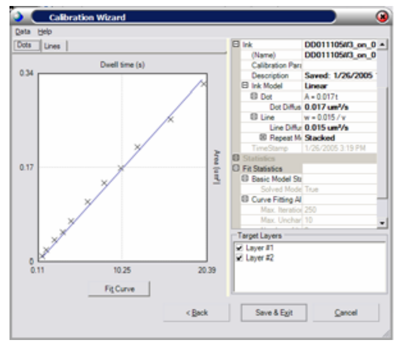

Fig. 2c – InkCal analysis window, linear fit

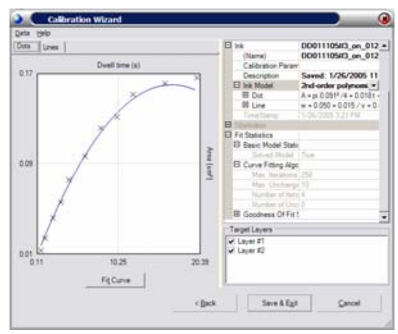

Fig. 2d – InkCal analysis window, 2nd order polynomial fit

Sample Experimental Data

Here we will show an example of two different ink calibrations:
pentaerythritoltetranitrate (PETN) on mica, and
mercaptohexadecanoic acid (MHA) on Au.

1. PETN Calibration (linear)

Deposition of thin films of energetic materials like PETN presented a challenging problem not only because they have never been patterned using the DPN method, but also because most explosives are sensitive organic molecules. Because they decompose at relatively low temperatures thermal deposition methods may not work. In our case, DPN was used to deposit PETN ink on mica as shown in the calibration below. In this study, InkCal was found to be very useful since the ink spread diffusively. The diffusion constant (D) was measured to be 0.083 µm^2/s.

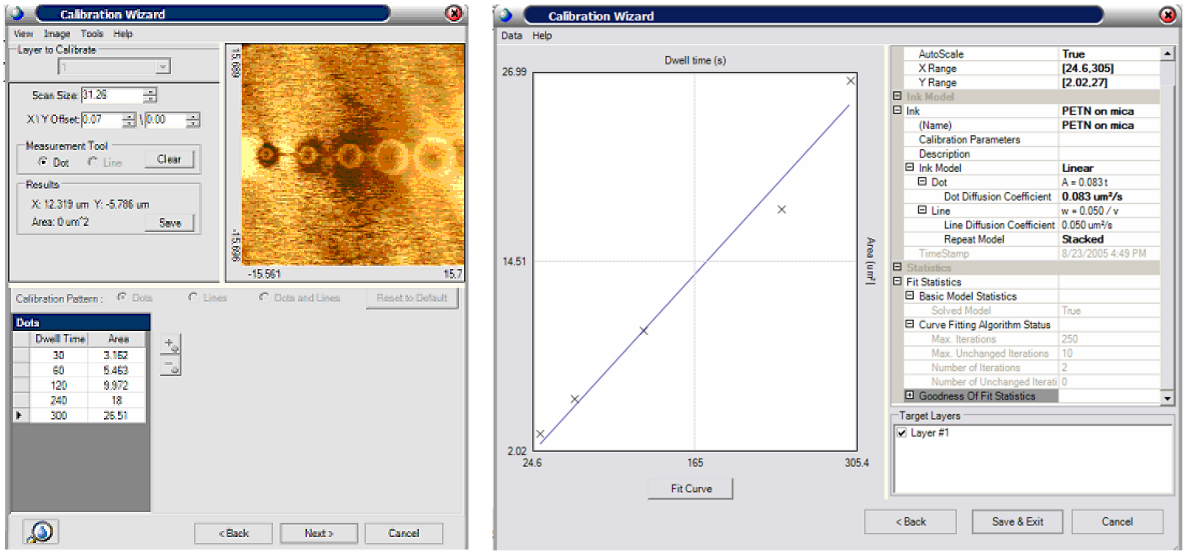

Fig. 3 – PETN on mica ink calibration

2. MHA Calibration (linear and second order polynomial)

MHA forms a self assembled monolayer on Au and has been established as a reliable ink. Typical diffusion constants of MHA ink on evaporated gold range from 0.01 to 0.08 $\mu m^2/s$. The data seen in Fig. 4 highlights not only the linearity of MHA deposition, but also how important it is to perform a "good" calibration. Fig. 4a shows the results of poor writing and sloppy measurement technique – offsets will lead to an inaccurate fit. Fig. 4b shows data acquired with high quality writing and consistent measurement technique. When these routines are followed, features can be patterned to within 1% of their specified size.

(a) **(b)**

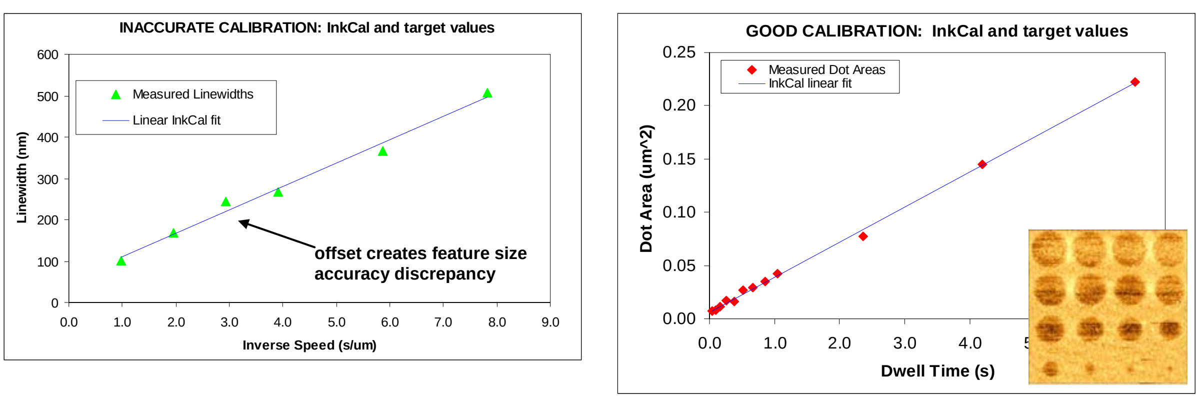

Fig.4: (a) Plot of line width vs. inverse tip speed illustrating the experimental conditions for an inaccurate ink calibration. (b) Plot of dot area vs. dwell time illustrating a good calibration (C = 0.033), which will lead to accurate writing of feature sizes; insert: array of dots used for calibration.

Conclusions

InkCal is a simple tool that calibrates ink diffusion in order to produce the desired features sizes in DPN patterns. This empirical routine is fast, easy to use, and avoids the requirement of manually calculating diffusion. Therefore, InkCal is a valuable efficiency tool for the refinement of ink formulations and also during the controlled patterning of more well developed ink systems. InkCal is useful for ink diffusion systems beyond the case of simple linear diffusion, and therefore useful beyond depositing alkanethiols on gold substrates.

For more information including pricing, please contact NanoInk Sales Department at sales@nanoink.net or 1-847-679-NANO.