Laser Direct Writing and Precision Pattern Alignment

Ron Hellekson, Cary Addington, Chuck Metge; Hewlett-Packard; Corvallis, Oregon, USA
Carl Picciotto, and Jun Gao; Hewlett-Packard Laboratories; Palo Alto, California, USA
Interactive Presentation

Abstract

There are many ways of using lasers to direct write or create an image of functional electronic material. However, one of the challenges of making electronic devices on flexible substrates is how to align one pattern with another pattern on a substrate which is dimensionally non uniform. We have developed a process that uses the initial pattern as an encoder for the subsequent pattern utilizing a unique algorithm called nDSE (nanometer Displacement Sensing and Estimation). We will show example of using this process in conjunction with laser delamination of thin metal from plastic substrate

Introduction

Thin films of metal (<100nm) on a polymer substrate can be delaminated from the polymer by means of a thermal shock event. With a single pulse of <30 nanoseconds and pulse energy densities of 200-500 milijoules/cm^2 the metal absorbs the radiation in such a short time a thermal shock wave actually delaminates the material. Figure 1 is a photograph of the material being uniformly lifted or delaminated from a polymer substrate.

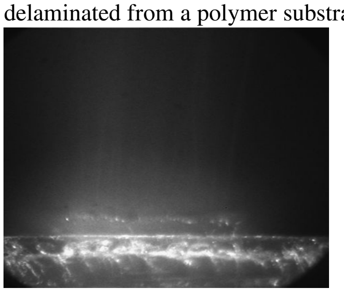

Figure 1: High speed image of the metal removal from polymer surface

A variety of metals (Au, Cu, Al, Ag) and polymer substrates (PEN, PET, ZF16, Polyimide) have been tested. Figure 2 shows 20 micron wide lines of Ag patterned with laser delamination.

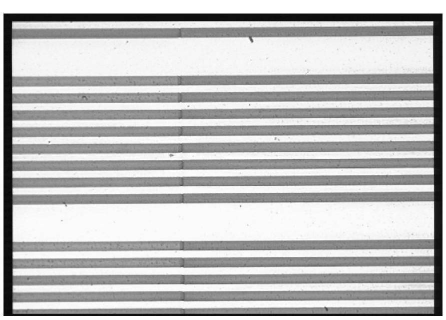

Figure 2: 20 micron metal lines (white space) and 20 micron spaces (dark space) created with laser delamination

Displacement and alignment algorithms

It is difficult to overlay circuit patterns to create well aligned transistor structures on a flexible substrate which is not dimensionally uniform or stable. One way to do this is to recognize an existing first level pattern and use this pattern as the position encoder for aligning further layers. The current approach uses two standard vision cameras and off the shelf optics to acquire images of the pattern. Then these images are compared using the nanoscale Displacement and Sensing and Estimation (nDSE) algorithms developed at HP Labs to create a correction offset value.

The nDSE algorithms calculate displacements of imaged objects (or pseudo-displacements between identical objects) to sub-pixel precision, using either phase analysis (using a technique the Labs engineers call PDD for Phase-Delay Detection) or spatial-domain image correlations. Single-digit nanoscale precisions are achievable with nDSE, though this application requires only moderately sub-micron precision.

PDD involves calculating the Fourier transform $\Im(u,v)$ of an image $f(x,y)$, and then solving for the (x_0,y_0) which minimizes the error of the following equality for the Fourier transform of the displaced image $f(x-x_0, y-y_0)$:

$$f(x-x_0, y-y_0) \Leftrightarrow e^{i2\pi(ux_0+vy_0)}\Im(u,v).$$

For the approach involving image correlations, an inverse cross-correlation surface is calculated by the following expression:

$$C_{i,j}^k = \sum_{m=1}^{M}\sum_{n=1}^{N}\left|r_{m,n} - c_{m-i,n-j}\right|^k,$$

where $r_{m,n}$ and $c_{m,n}$ represent the reference and comparison frames, and the exponent k is generally 2. The surface is fitted to a second-order Taylor expansion, and the location of the minimum of this surface is calculated, giving us the estimated displacement.

We use these displacement measurements to achieve absolute overlay alignment as follows. Suppose we have fabricated an array (Layer1) of identical patterns (4 squares arranged in a quadrant equally spaced = image) on a substrate. After subsequent processing, the array might look like Figure 3 due to substrate distortions caused by lack of thermal stability:

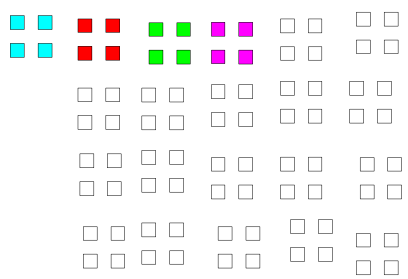

Figure 3: Layer 1 showing pattern distortion due to processing subsequent to original creation of the pattern

Suppose we now wish to create on a next layer (layer 2), a cross pattern ('+'), placed in the center of each field. To achieve layer-to-layer registration, we use a look-ahead camera which allows us to follow the distortion of the substrate by tracking the field-to-field displacements of the first-layer patterns using nDSE displacement measurements. The look-ahead camera is positioned as illustrated in Figure 4 below:

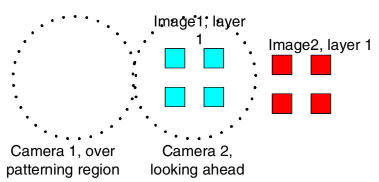

Figure 4: Arrangement of cameras showing part of the entire array used to track field to field displacements.

The image at the look-ahead camera (Camera 2 in the illustration) is acquired and stored. The substrate (or the patterned array) is then translated by the nominal inter-field distance, and a Layer 2 cross pattern is fabricated at Camera 1 as shown in the following Figure 5:

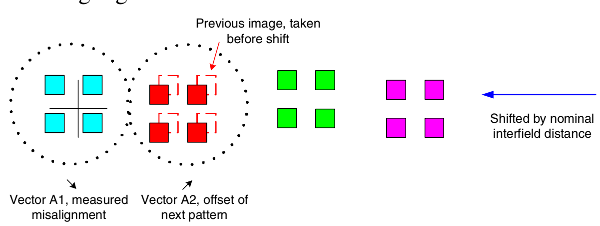

Figure 5: Layer 2 cross pattern fabricated at Camera 1 location and not properly aligned.

At this point, we do not expect to see ideal alignment. Our goal is to ensure that the next field achieves a high degree of alignment. We must derive exact shift vector required to bring the next field into the proper position for alignment. Through Camera 1 we now inspect the degree of misalignment using any available inspection tool. We record the misalignment as Vector A1. Using nDSE processing on the Camera 2 images, we determine Vector A2, the offset of the next pattern with respect to the initial pattern taken before the shift. Vector addition of the previous substrate shift with vectors A1 and A2 will yield the shift necessary to bring the next pattern into proper alignment. In this case, the result is a slightly shorter shift. We now store-away the current image at Camera 2 for use as a reference for the next iteration, and then we shift the substrate by the corrected shift vector, and fabricate the next Layer 2 cross pattern shown in Figure 6:

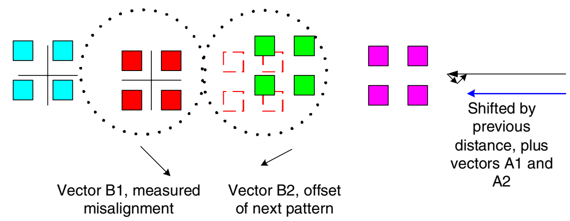

Figure 6: Layer 2 cross pattern fabricated at Camera 1 location and properly aligned on field 2.

Precise alignment of the second field is achieved. Figure 7 shows the next iteration to align the third field :

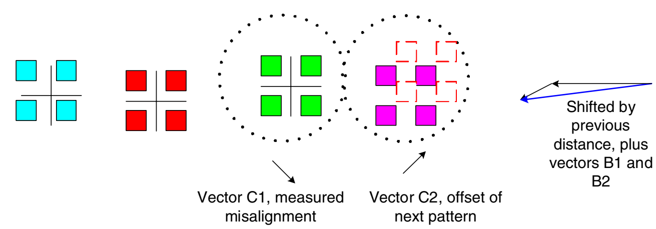

Figure 7: Second iteration of using nDSE and vector addition to align layer 2 cross pattern on the third field.

When we've stepped-through and patterned all fields, the substrate should look like this:

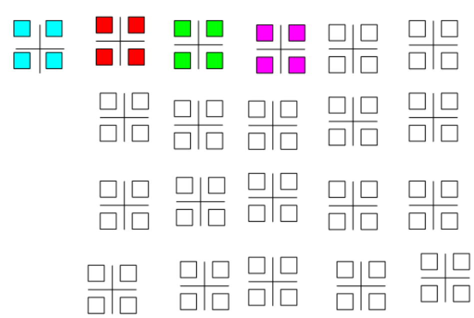

Figure 8: Completed array with cross patterns overlaid on original layer 1 which was distorted due to processing.

We have achieved precision overlay of Layer 2 over Layer 1, using relative displacement measurements on arbitrary features. No special alignment targets were required. Notice the mis-aligned field in the upper-left, a sacrificial field used for alignment calibration.

Experimental Approach

To test the alignment approach discussed above we created a set of nested vernier patterns with 1 micron resolution, which were imaged using the laser delamination approach discussed above. The verniers were imaged as a set of repeating patterns into a thin film (70nm) of Ag on a non heat stabilized PET substrate that was 25 microns in thickness. The patterns were imaged across an area that was about 10 inches square. The vernier patterns which nest inside one another are shown in the following figure 9.

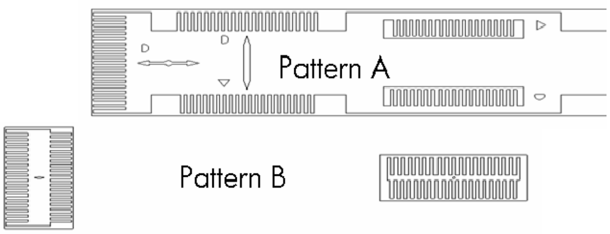

Figure 9: Vernier patterns used to test alignment algorithms. The horizontal and vertical arrows in Pattern A are the zero reference for the verniers.

The following photo, figure 10, is an actual image of Pattern B nested inside Pattern A. The photo shows most of 3 repeats of the nested patterns.

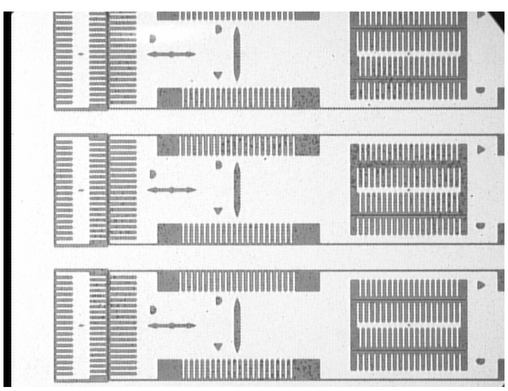

Figure 10: Nested vernier patterns where the dark areas are places with the Ag removed.

We have done some initial testing using this approach. The following figure shows about 5 microns of misalignment due to such things as re-fixturing of the part and handling.

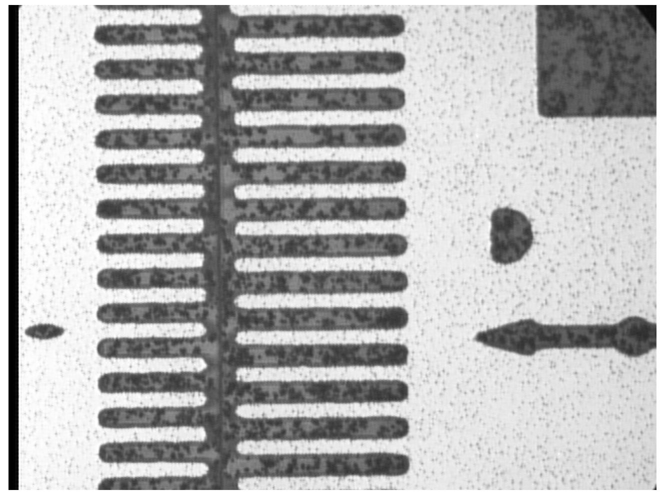

Figure 11: The arrowhead is the zero reference and note that the first set of verniers to align is about the 5^{th} one above the arrow, or about 5 microns.

With the use of the nDSE algorithm, we have been able to achieve about 1 micron of mis-registration on a limited sample as shown in the following photo.

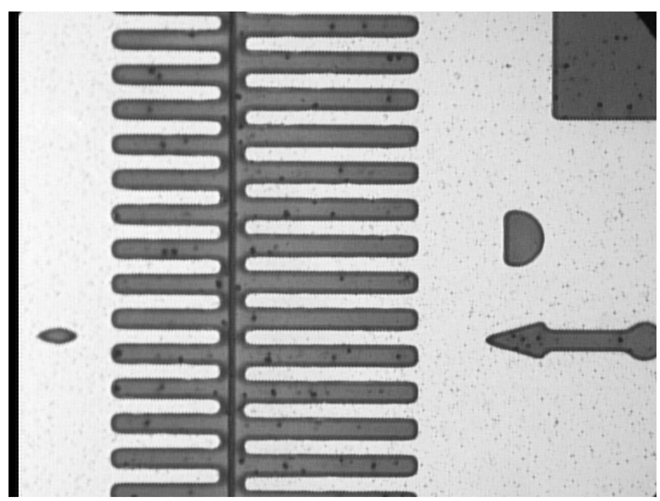

Figure 12: The arrowhead is the zero reference. Notice that the zero reference is almost correctly aligned. Under higher magnification it can be seen that the alignment is off by about 1 micron as the finger adjacent to the zero reference is in better alignment.

Conclusions

Our testing and evaluation has just begun. Preliminary results are extremely encouraging, though it is still too early to draw truly conclusive judgments. In the weeks ahead, we will work to characterize sources of experimental error, and to collect statistically meaningful data to explore the practical limits of this technique on non-dimensionally-stable substrates. Multi-layer device fabrication on non dimensionally stable flexible substrates will require new pattern alignment techniques, and HP's nDSE-based technique will be an important contender in providing this capability."

References

[1] Gao, J., Picciotto, C., Jackson, W., "Displacement sensing and estimation theory and applications", Applied Physics A 80, 1265-1278 (2005).

[2] Picciotto, C., Gao, J., Hoarau, E., Wu, W., "Image displacement sensing (NDSE) for achieving overlay alignment", Applied Physics A 80, 1287-1998 (2005).

In addition to the above references some of this work was originally reported at an in house HP technical conference whose proceedings are not publicly available.

Author Biography

Ron Hellekson, Cary Addington, Chuck Metge all work in inkjet product development in Corvallis, Oregon and have over 10 years experience each in process development of lasers, vision systems and precision alignment techniques.

Jun Gao and Carl Picciotto work for HP Labs in Palo Alto, California and have been working in the area of displacement sensing for over 6 years.