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Three-Dimensional Reconstruction of Printed Circuit Boards: Comparative Study between 3D Femtosecond Laser Serial Sectioning and Optical Imaging versus 3D X-Ray Computed Tomography

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Introduction: Reverse Engineering of printed circuit boards or PCBs has become increasingly important for hardware security, quality assurance and failure analysis purposes. [1] Existing imaging techniques for reverse engineering of PCBs include two major approaches of nondestructive 3D Xray Imaging [2,3] and destructive delayering usually using mechanical polishing and optical imaging. [4] Both methods face several challenges. Firstly, PCBs typically consist of multiple layers of heterogeneous materials including metal (e.g., copper), plastics, and glass fibers. The significant variation between X-ray absorption coefficients of the PCB materials prevents the lower Z (atomic number) materials to be imaged effectively in presence of higher X-ray attenuating materials such as copper. Beam hardening artifacts, high aspect ratio and size challenges also make Xray microscopy more difficult. [2,3] Destructive methods on the other hand are time consuming and labor intensive. They also demand highly skilled individuals to perform the task and nevertheless involve many try and error sessions and each sample requires its own recipe development process [4] In this paper we introduce a fully automated process using serial sectioning by femtosecond lasers for delayering combined with optical imaging as an alternative solution and compare results with those of obtained by high quality 3D Xray Microscopy.

Method: The process developed utilizes a femtosecond laser machining system equipped with a digital microscope and a gas processing system to eliminate redeposition. All aspects of the method are automated within an intelligent algorithm allowing the effective coordination between delayering, gas processing and imaging which also controls a three-dimensional stage system for transferring the PCB between the laser scan field and the microscope. The process is outlined as such 1) The PCB is placed on the vacuum stage and imaged by the digital microscope (2) The operator selects an area and creates a CAD at the ROI for lasering (3) Based on the size of the CAD the software will automatically decide how many images to stich to image the full ROI (4) Sample is translated to a confocal height sensor to focus the laser (5) Sample transfers to laser scanner system – lasering begins (6) Post lasering the area is cleaned with gas processing (7) Sample translated to the microscope and ROI imaged (8) This cycle (4-7) will repeat until the full ROI is imaged and removed. Many key concepts including laser parameters, scanning parameters and gas processing in tandem with laser processing have been optimized and will be discussed in detail in the full paper. The system is designed to be able to go through the process of optimization automatically.

For the data set presented each lasering cycle took 2 minutes for a 1.5 x 1.5 cm area of the PCB. This time is dependent on the scan speed of the laser scanner system. The scan speed in this workflow was chosen as a result of a laser parameter optimization process. However, the cycle time can easily be decreased further in numerous ways, such as increasing the repetition rate of the laser and scan speed simultaneously, or by applying other scanner technologies such as polygon scanning. After each lasering cycle transfer to and from the digital microscope and image time was ~30 seconds. This time is dependent on the resolution or field of view needed and consequently the number of images which are taken and stitched together. In this case a 7-um lateral resolution was selected and 4 images taken and stitched at each step creating the 1.5 x 1.5 cm field of view.

Results: A total of 1520 images taken equating to 380 cycles were gathered and utilized to create a three-dimensional volume with a depth of 1 mm. The total process took 19 hours to complete. However as mentioned earlier, process times again can be significantly reduced if larger regions of interest or depths are needed. Also, because this process is completely automatic there is no need of any operator's intervention. Various slices from the performed delaying representing different internal layers of the PCB are shown below, Figure 1.

Once all slices have been obtained, they are stacked together and reconstructed to form a three-dimensional dataset. This data set has been compared with high resolution XCT of the same exact region obtained prior to delayering. A representative slice is shown in Figure 2. The optical image slice match perfectly with the 3D Xray slice suggesting that the destructive process has not altered key elements of the PCB. In addition, the optical data contain more texture information and can resolve the plastic and fiber glass information unlike the Xray method [5].

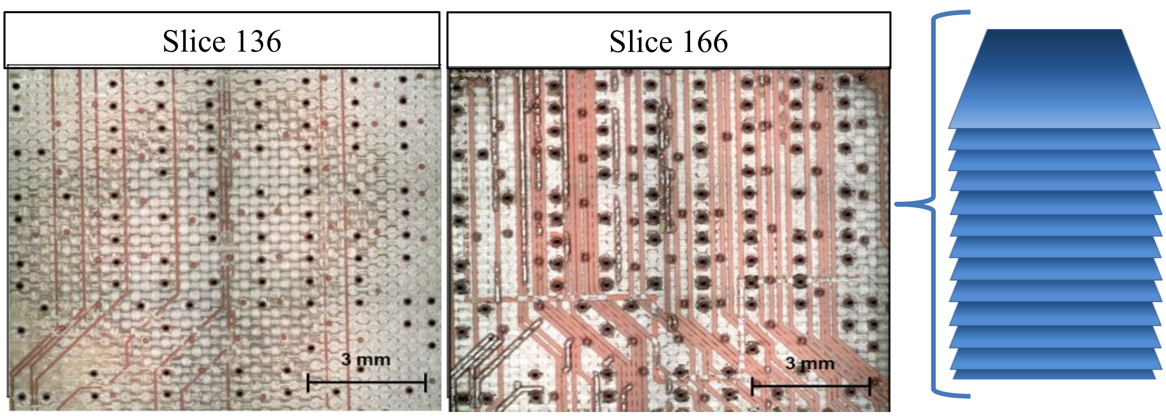

Figure 1. Digital microscope images of various slices obtained from delayering process and schematic depicting the stack of each slice fore three-dimensional reconstruction

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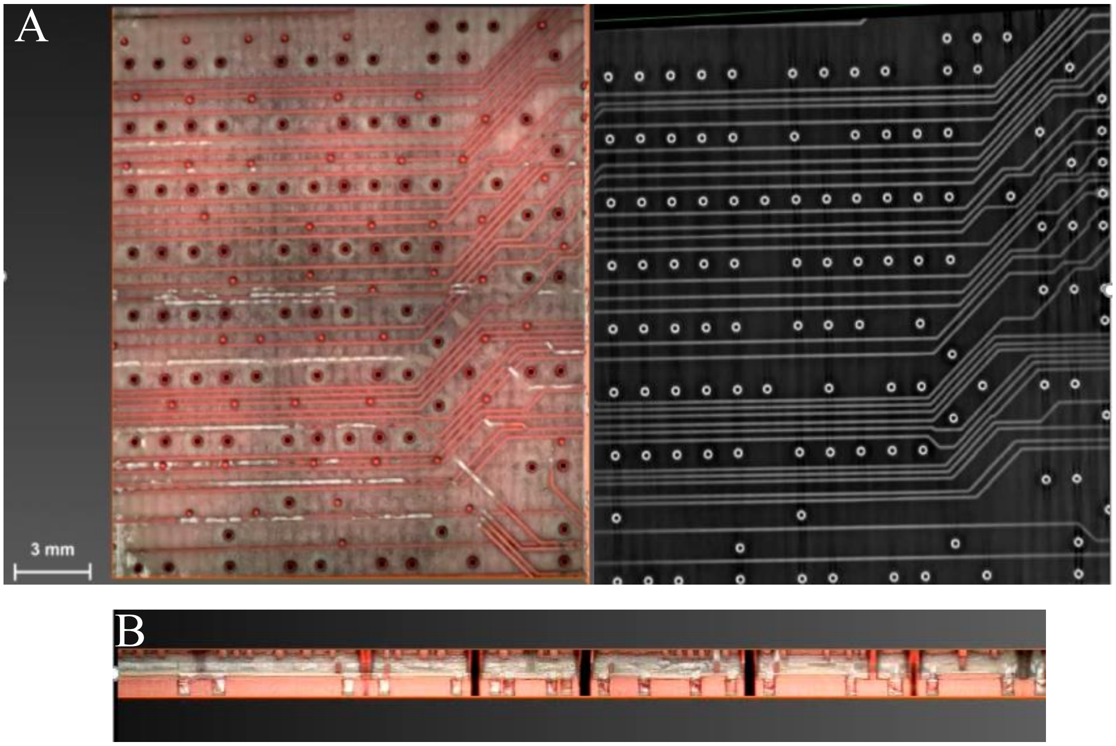

Figure 2. A. Side-by-side of reconstructed volume and XCT B. Cross-sectional view of reconstructed volume.

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