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Subtleties of machining silicon for inkjet technology

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Abstract

We will discuss the subtleties of processing silicon for thermal inkjet print cartridges. Topics will range from selecting the proper light source for wafer marking to obtain required quality. The advantages and process set up conditions for stealth dicing wafers, with a deeper dive into aspects around precision micromachining of long, narrow, high aspect ratio channels. Here, we will review how particular laser beam parameters affect the channel quality and their correlation to removal rates for a particular process. To produce these long, narrow features, an assist process is of utmost importance. Details of why this novel assist process is used will also be covered.

Keywords: Laser processing; Silicon; Ablation; Marking; Stealth Dicing; Micromachining; Assist;

1. Introduction

Silicon is the base material for today’s electronics. This paper will discuss some of the laser manufacturing processes of silicon used to produce a thermal inkjet print cartridge. These examples will range from well-known processes such as wafer marking and explaining the importance of part tracking along with selection of the correct laser and the quality of said marks. Another application that is gaining popularity due to the push towards thin wafers is stealth dicing. We will discuss the differences, advantages and disadvantages between ablation and stealth processes along with limitations of each. The final topic will be around micromachining narrow, high aspect ratio (5:1) trenches in silicon. How it is done, what are the critical parameters and how water assist makes this into a viable process.

1.1. Wafer Marking

The importance of identification marking is often overlooked in the big picture of manufacturing, but it is one of the core processes that needs to work with low occurrences of poor-quality processing. Without the proper identification of components, many processes, automation lines and factories would come to an immediate halt. In today's manufacturing world, laser part marking is mainstream. With so many manufacturers that make off the shelf marking tools, it allows potential buyers to obtain a tool without knowing what the fundamentals are for proper operation. Below in figure 1 (a-d), shows several different qualities of marking. Figure 1a is a high-quality mark with read scores in the high 90's for all alpha-numeric characters, the marking quality begins to deteriorate as seen in figures 1b & 1c. In both figures, the mark is considered out of control and parts would begin to be rejected. It was found that the laser was greatly overpowered for the process causing ablation and debris to form the wafer. The technicians reduced the power to achieve proper marking, but then found the tool produced variable marks due to the power being unstable at that setting. After identifying the issue, a lower power laser was acquired and installed in the tool. Read marks in the factory now exceed 99%.

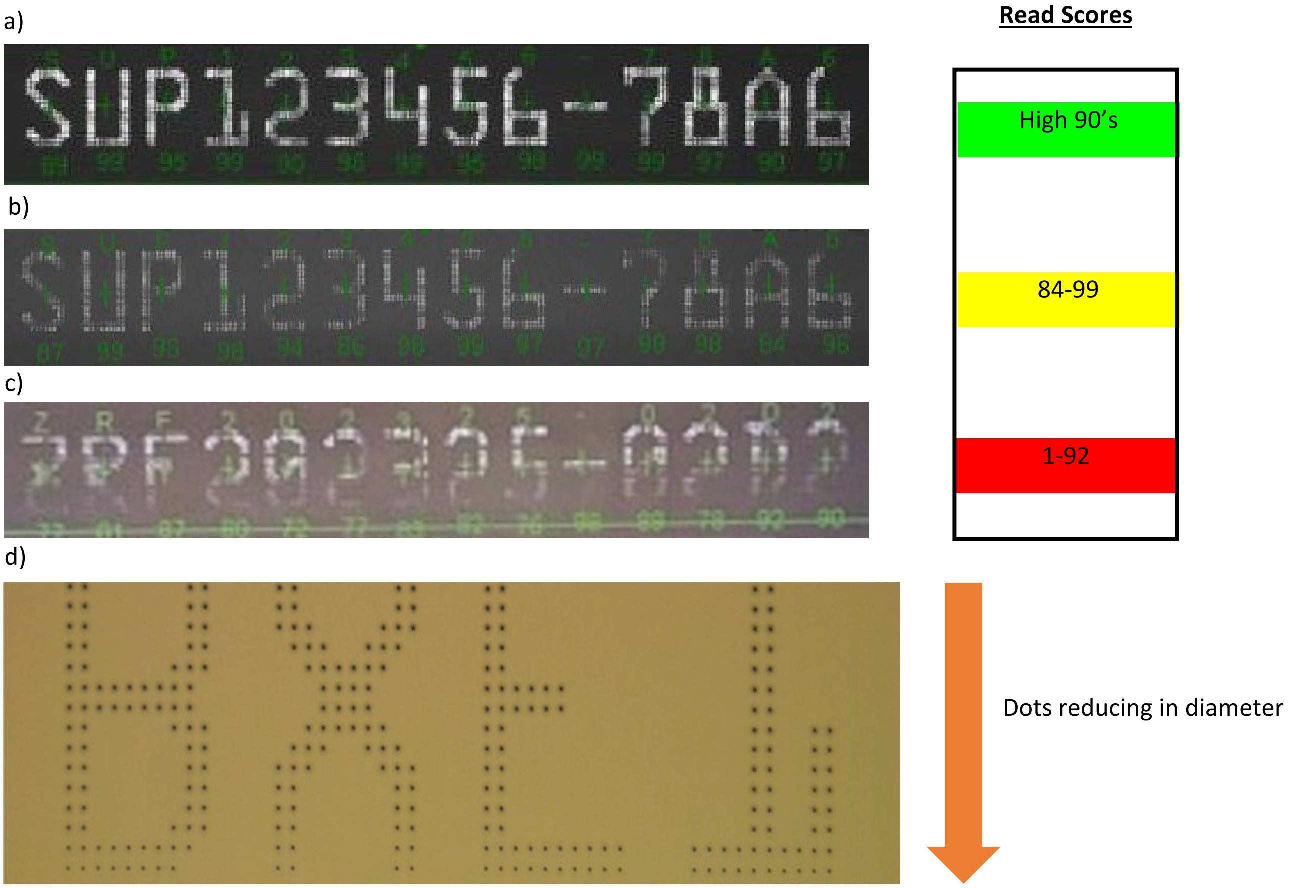

Fig. 1. a) 2W laser running at ~1.5W – Acceptable b) 10W laser running at ~1.5W – Threshold of Acceptable c) 10W laser running at ~1.5W – Failure d) Enlarged image of the 10W laser running at ~1.5W.

1.2. Stealth dicing

Stealth dicing is becoming mainstream with industry using thinner wafers. This technology is typically suitable for wafers thinner than 200µm. Unlike laser ablation, stealth dicing creates a stress point defect within the substrate that does not produce debris. At a later step, external stress is applied to the wafer causing the defect line to propagate until the wafer thickness is fully singulated. A distinct advantage of stealth dicing is the saw street widths are drastically reduced compared to blade dicing. 200 µm a common range for blade dicing, with stealth dicing the streets are reduced to 20µm's. With smaller saw streets, a manufacturer can add more devices to the wafer. Other advantages are the high speed at which the defects can be induced. A typical processing rate is approximately 700mm/s, no use of consumables and post cleaning steps are not required. Below (figure 2) shows a cross section of a 150µm silicon wafer that has been stealth diced. This shows two different defect zones resulting from a two-pass process. Additional passes are used to assure that the crack will propagate on the intended plane.


Second Pass – Multi-photon absorption Less damage due to relieving the stress

First Pass – Multi-photon absorption Creating a damage line of residual stress

Fig. 2. cross section of 150um thick silicon wafer using 2 pass stealth dicing process

Even though stealth dicing and ablation are both laser-based processes, they are not the same when it comes to dicing. Laser ablation interacts with the surface of the wafer. This technique has a strong advantage over stealth dicing if the saw streets have low k materials applied or features in the path. Laser ablation will cut through the films and can also be combined with traditional blade dicing. Disadvantages include debris on the surface that may lead to scratching and there is a required wet clean process post ablation. Stealth dicing has practical limitations to <200µm thick wafers. Full thickness dicing is possible but will require several passes to obtain a quality cleave at singulation. These additional passes far exceed the cycle time that blade dicing can achieve.

1.3. Micromachining of silicon

In this embodiment a fluidic slot is produced so that ink will flow from the ink delivery system (IDS) through the silicon to the front of the wafer where the thin-films and the microfluidic routing defined by SU8 are located. This is a two-step process that uses a combination of laser and wet etch. As illustrated in figure 3, the MEMS device on the front of the silicon has previously been created. Laser is used for bulk silicon removal to create a narrow, high aspect ratio trench that leaves a web of silicon at the bottom. The wafer is placed in a wet etch bath where the silicon web is etched away, creating the fluidic channel to the front side of the device while the manifold assumes its final shape.

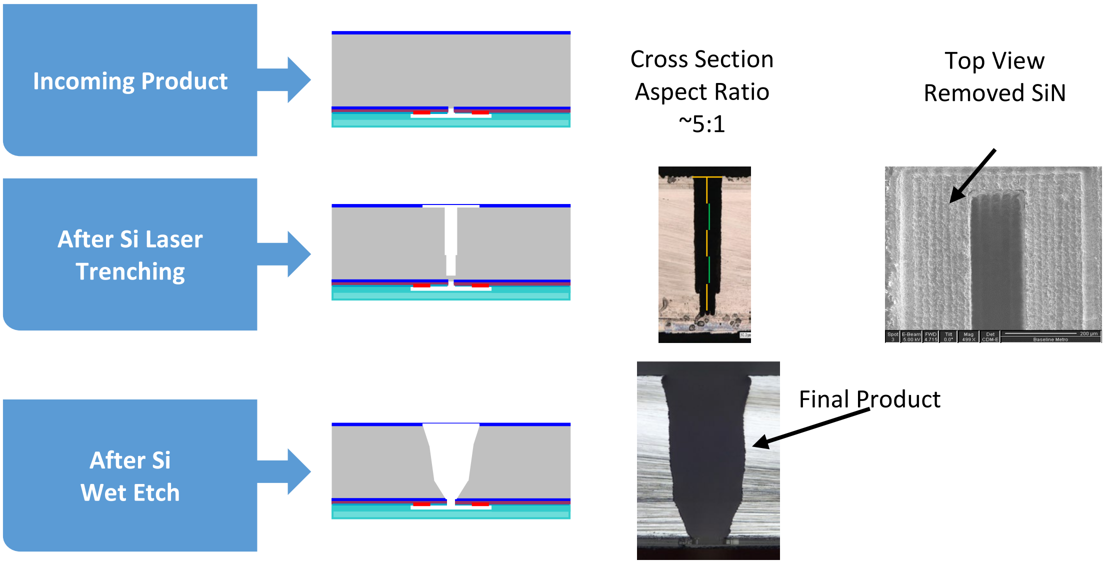

Fig.3. process steps to create an inkfeed slot through silicon

It is important to understand the fundamental relationship between the light and material to create a stable process. The graph in figure 4 is the absorption depth in silicon. The most common lasers used for micromachining silicon are Q-switched DPSS lasers, typically Nd:YAG or Nd:YVO$_4$ that fundamentally produces 1064nm with a second harmonic at 532nm and a third harmonic at 355nm. The curve shows that 355nm and 532nm have strong absorption in silicon.

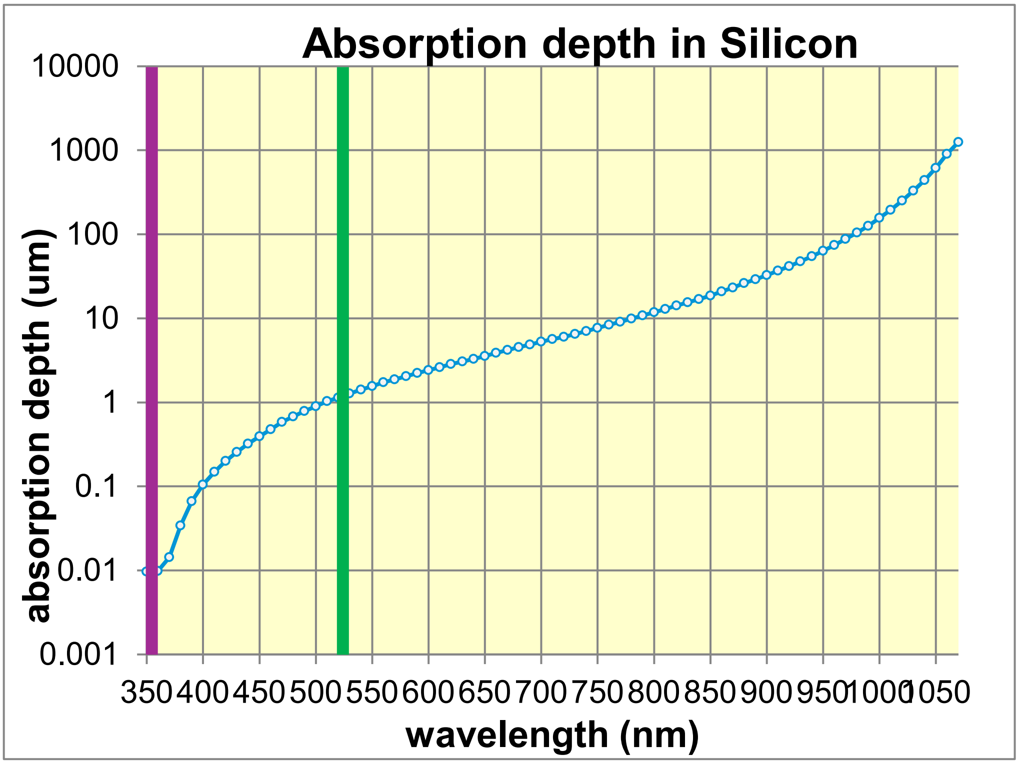

Fig.4. absorption depth in silicon

Focusing on 532nm, the graph in figure 5 shows a typical ablation rate curve when plotted against fluence. For critical micromachining geometries, one would select a fluence that is above the knee of the curve to create a process that is less susceptible to pulse energy/fluence variation. It is very important to have processing fluence well below the explosive boiling regime due to its uncontrolled processing area.

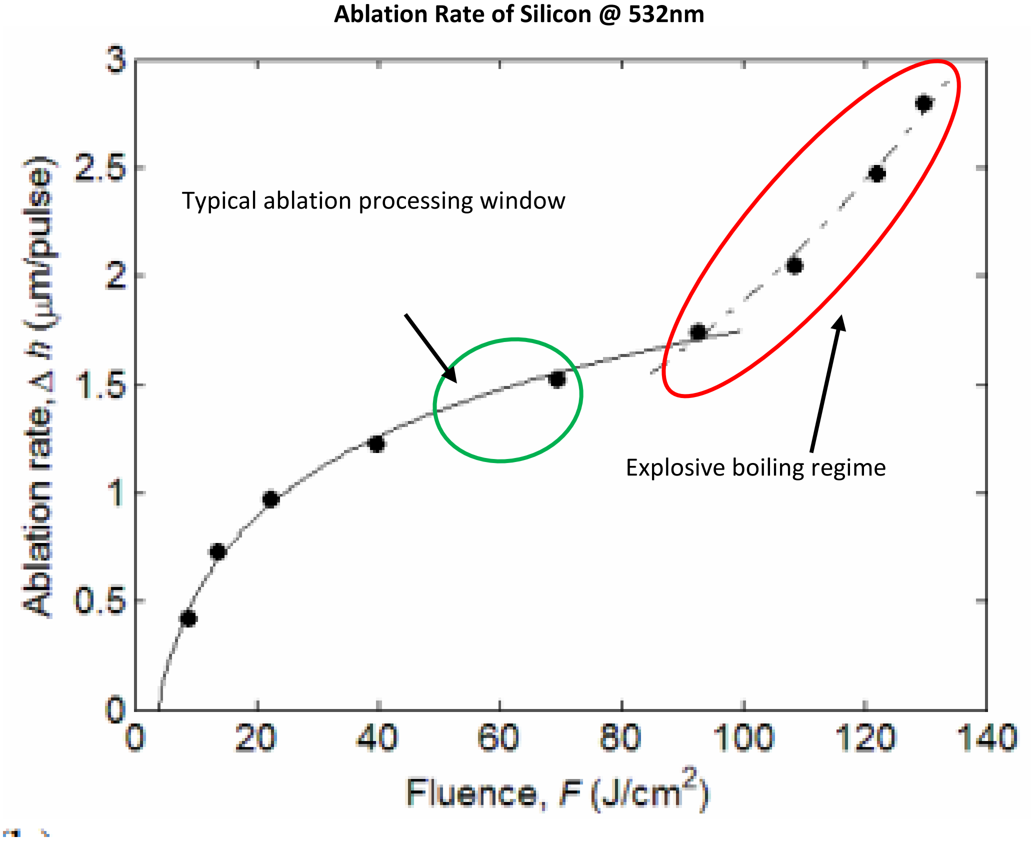

Fig. 5. ablation rate of silicon at 532nm

When creating such a process, tradeoffs to be able to control variations in a process are mandatory. Figure 6 displays the ablation rate curve for a given pulse overlap and pulse length that has been determined by previous experimentation. For this particular curve of inputs, 7µm/pass is a stable removal rate for a large range of fluences. Where it is easy to increase the removal rate/pass, with additional overlap created by a slower scan speed, one then loses resolution to control the depth of the trench.

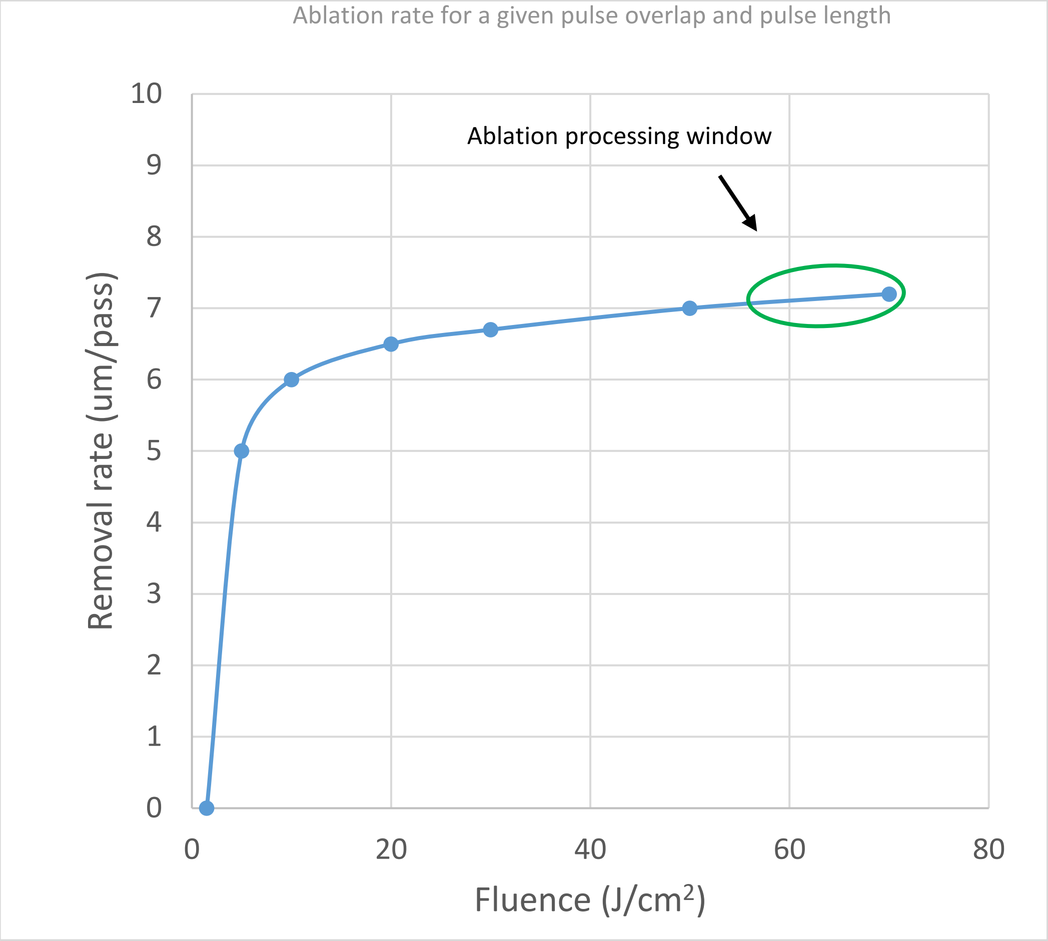

Fig. 6. silicon removal rate per pass

Many laser processes benefit from an assist process. Common methods usually involve gas, whether it is an inert gas to reduce oxide growth, fluorocarbons to create laser assisted etching or high purity oxygen to perform exothermic cutting. In this scenario, a water assist process was developed to reduce HP's usage of fluorocarbons. Figure 7 shows that the assist shoe also encompasses vacuum ports to extract the water used during the micromachining process.

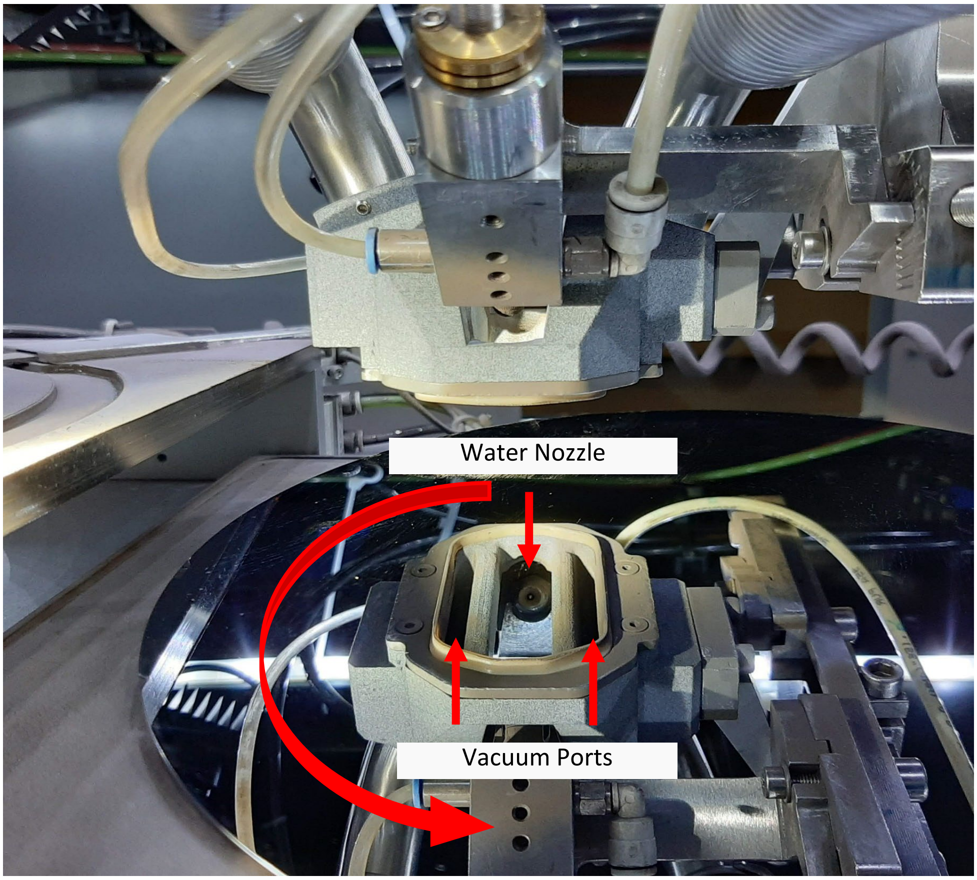

Fig. 7. assist shoe that incorporates water nozzles and extraction ports

It has been found that the addition of water mist greatly improves the consistency of the feature geometry along with depth control. Figure 8 shows a cross-section of the consistency across the wafer when using water compared to air and vacuum alone. In figure 9 & 10 is a magnified version that shows the drastic difference between the two assist process

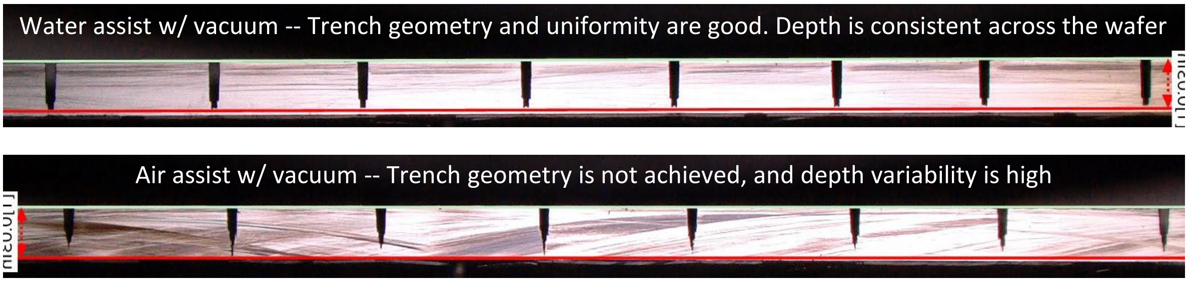

Fig. 8. consistency differences between water and air assist

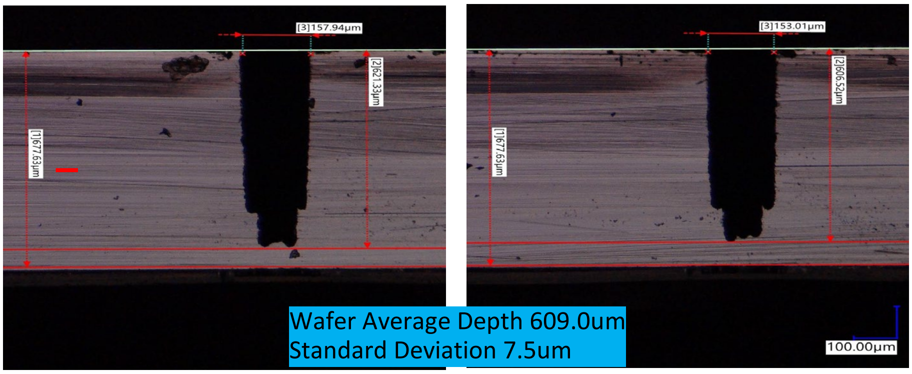

Fig. 9. water assist variation

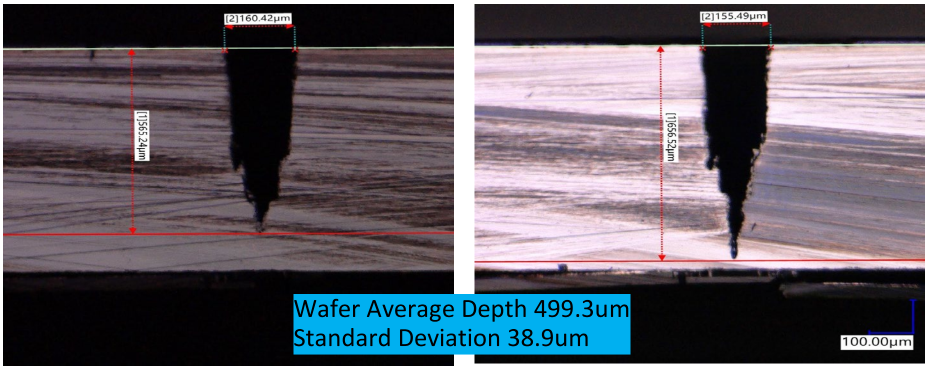

Fig. 10. air assist variation

In our findings, pulse length and energy distribution have a profound effect on the ablation efficiency of this micromachining process. Figure 11 illustrates the energy distribution for a fixed energy pulse, where the pulse length varies. For a TEM_{00} Gaussian pulse, setting the overall energy just above the ablation threshold does not ablate much material. If the pulse becomes shorter, while keeping the pulse energy the same, the peak energy is near saturation providing optimum efficiency as shown in the “medium pulse” illustration. When the pulse becomes even shorter, the peak energy increases again, but this time the removal rate of the silicon begins to diminish. This is due to the peak of the Gaussian beam is significantly in the material saturation regime, which does not remove any additional material and now becomes time dependent. Shorter interaction with the material produces a reduction in ablation rate per pulse shown in figure 12.

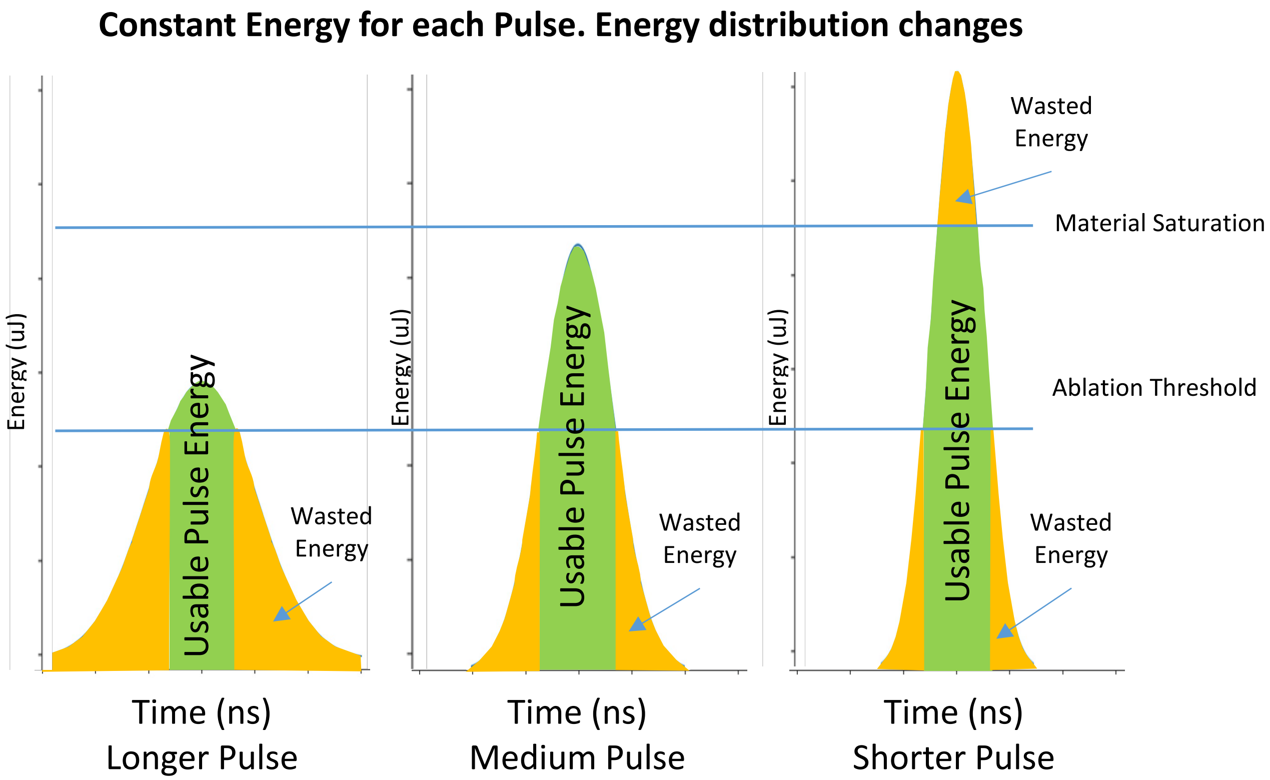

Fig .11. energy distribution of various pulse length

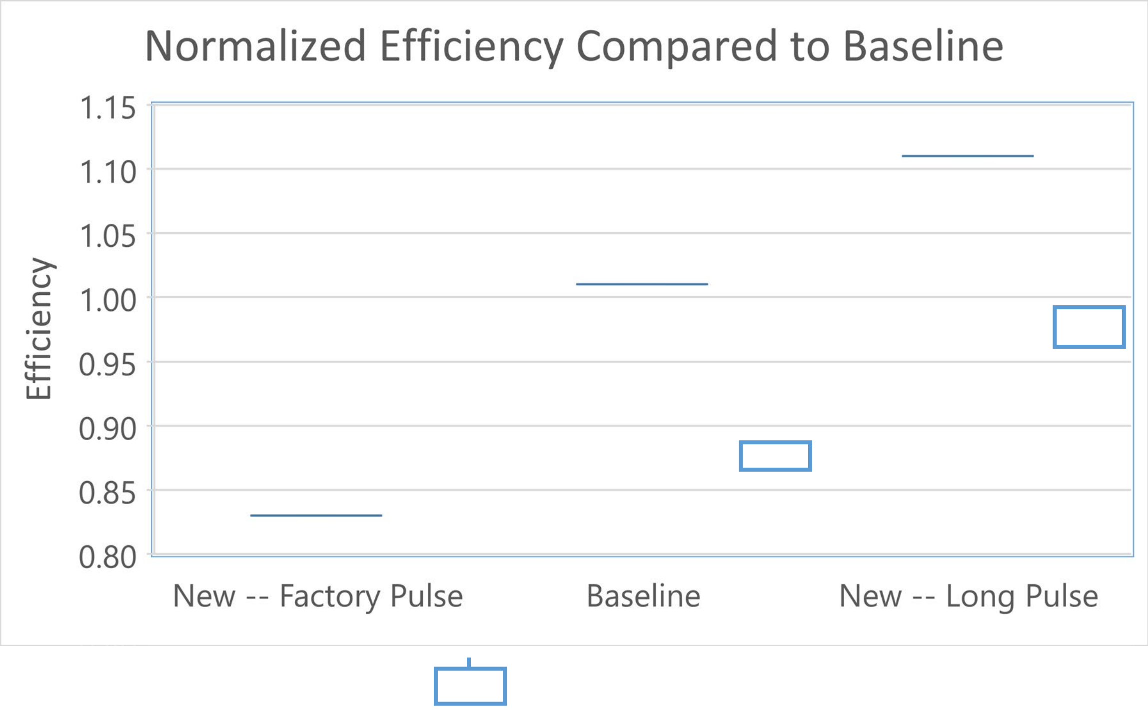

Fig. 12. normalized efficiency for silicon based on pulse length/energy distribution.

1.4. Conclusion

Lasers are used in many areas to manufacture thermal inkjet print cartridges at HP. This paper discussed some of our more common processes focused on silicon. There are many different material sets where lasers are used within our manufacturing and research sites. One of the most unique processes is the blind trenching in silicon. Many years were spent to perfect this process. Several of the parameters that were discussed in this paper such as fluence, energy distribution and assist are absolutely critical to make this a capable process.

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