CHAPTER II

FUNDAMETALS

With introduction of Giant Magnetoresistive (GMR) technology in IBM disk drive in 1997, the impressive increases in the areal density of disk drives are expected to continue. The areal density increase has been achieved by shrinking sensor dimensions as well as developing new magnetic materials and improving head design. To sustain such progress, the technology of recording head fabrication will need to advance at a rapid pace. One desired improvement involves the use of dry-etching processes in fabricating high-density recording heads [1].

Recording heads are usually fabricated on Al_2O_3/TiC (AlTiC) ceramic wafers, which provide excellent mechanical and tribological properties. AlTiC wafer is widely used as the substrate in thin film magnetic heads due to its high hardness and high wear resistance. Its mainly contains about 70% Al_2O_3 and 30% TiC. Recording heads are eventually formed into sliders that mounted on a suspension "fly" over magnetic disks to perform "read" (retrieve) and "write" (record) functions.

2.1 Photolithography and Etching Process Overview

Theory of aerodynamic was applied with magnetic recording design. Key process to maintain the flying height between magnetic recording and disk is making of patterning on substrate.

Process step to make a patterning on substrate is shown in Figure 2.1.

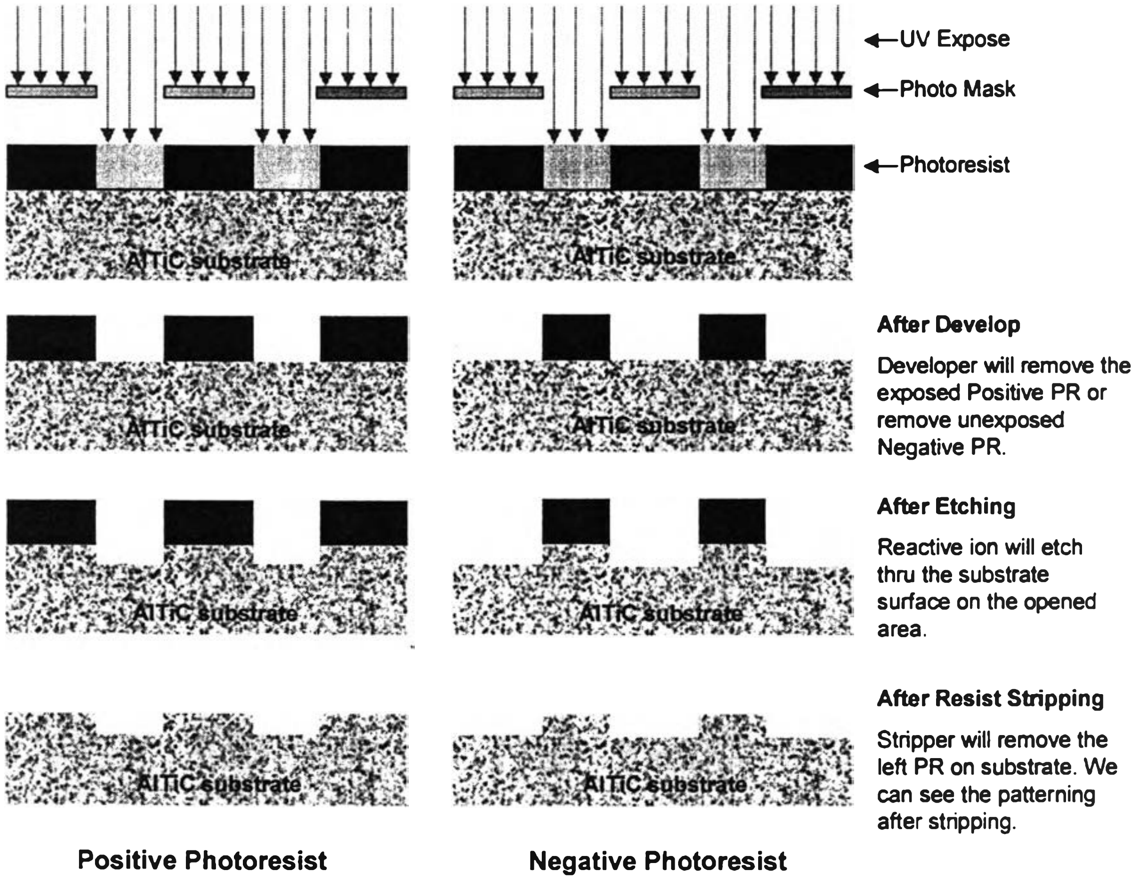

Figure 2.1. Illustration of photolithography and dry-etching process on AlTiC substrate.

- Apply photoresist on AlTiC substrate either positive resist or negative resist.
- Expose UV on the photoresist through the patterning mask.
- Develop the pattern to open area for etching process.
- Etch through the opened area.
- Strip the rest photoresist on substrate.

After the etching process is finished and the parts are stripped of all photoresist residues, the patterning which different depth can be observed on magnetic recording head such as illustrated in Figure 2.2. Suitable patterns and etched steps on the ABS of magnetic head slider can keep the slider flying on magnetic disk surface with extremely low and constant flying height in a hard disk drive.

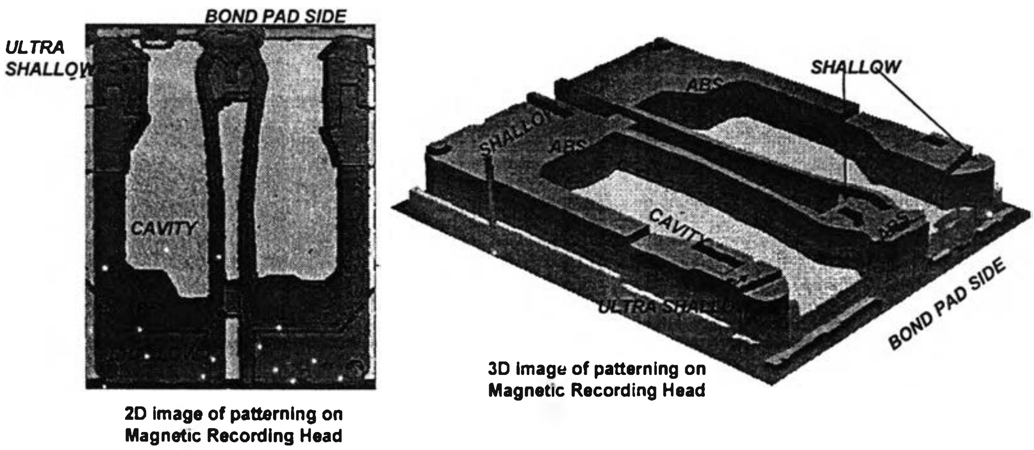

Figure 2.2. 2-D and 3-D images of the ABS as rendered by the white light interferometry are shown.

2.2 Reactive Ion Etching (RIE)

The schematic of the reactive ion etching reactor are described in Figure 2.3. Etching is consisted of three steps [7] as shown in Figure 2.4.

- Mass transport of reactants (through a boundary layer) to the surface to be etched.
- Reaction between reactants and the film(s) to be etched at the surface
- Mass transport of reaction products from the surface through the surface boundary layer

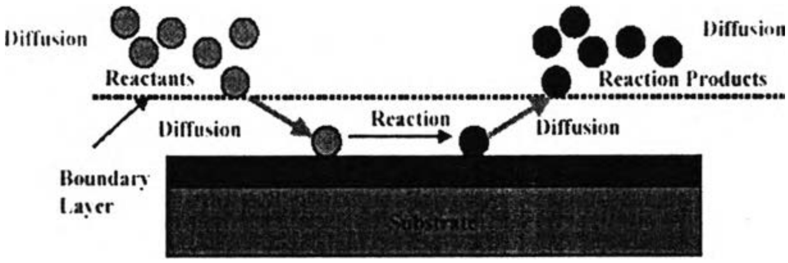

Figure 2.3. A schematic of the reaction mechanism of RIE is shown. [7]

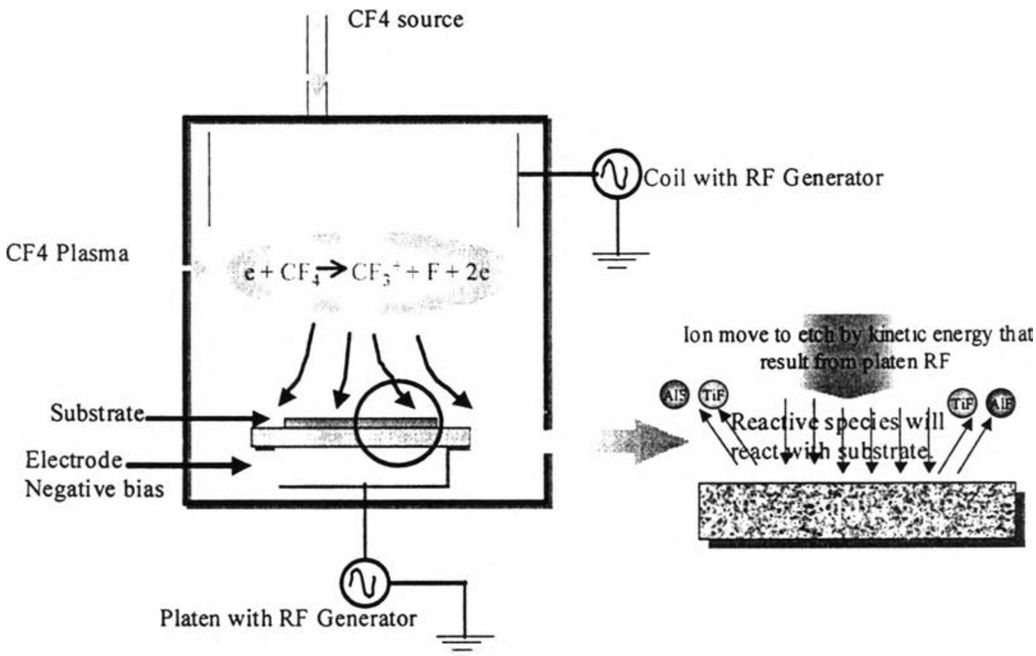

Figure 2.4. A schematic of the RIE chamber is shown.

2.3. Post-Etched Residue (or Redeposit)

Since ion etching is a physical etching process, the etched material usually accumulates on the first surface. Such "redeposit" typically forms on the sidewalls of features being formed and on the sidewall of their masks. Formation of nonvolatile fluorocarbons that deposit on the surfaces has been studied and identified to be similar to the polymerization reaction [8]. Fluorocarbon films deposits on all surfaces, but the ion velocity is nearly vertical. As a result, as the etching proceeds there is little ion bombardment of the sidewalls and the fluorocarbon film accumulates. (See Figure 2.5 for illustrations.)

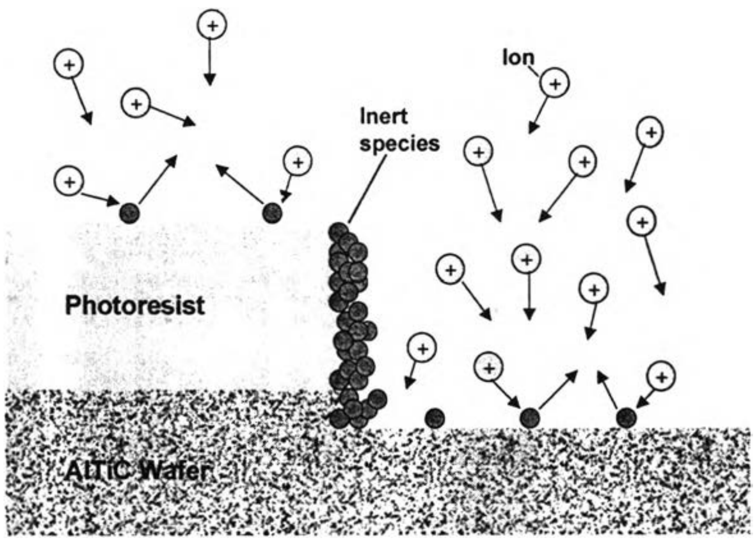

Figure 2.5. A schematic illustrating how redeposit is generated and accumulated on etched sidewall. [8]

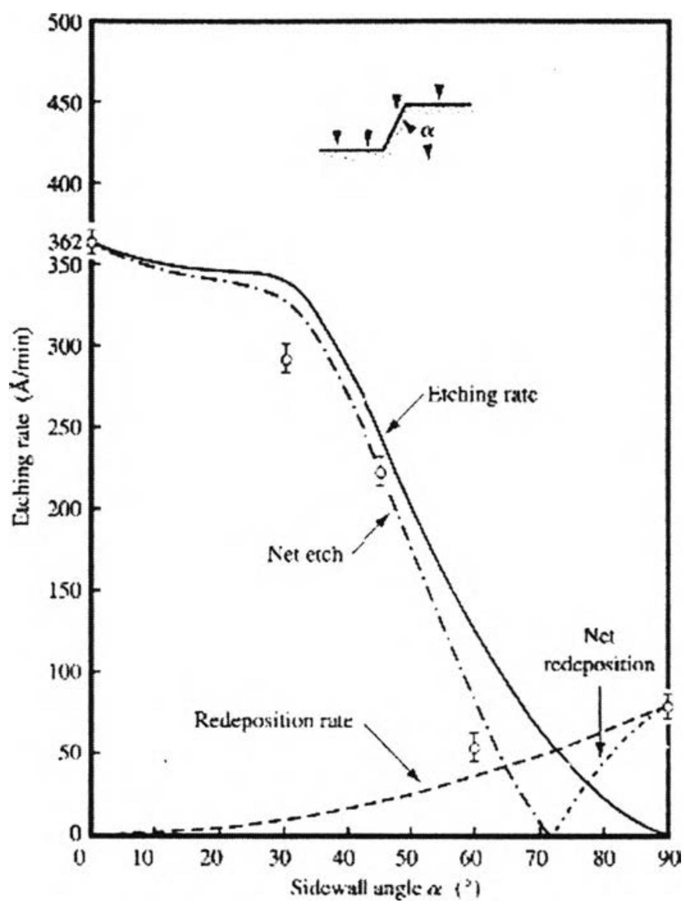

Figure 2.6. Illustration of sidewall etching and redepostion versus incident angle measured with respect to the normal of the sidewall surface. [3]

Figure 2.6 illustrates the balance of sidewall etching and redeposition for gold etching. [3] The net redeposition rate is subtracted from the measured etching rate to establish a "net etch rate" of the sidewalls. As an example, when the sidewall surface normal is at 30° with respect to the incident beam – for a vertical sidewall, this angle is the complement of the angle between the ion beam and the wafer surface normal – the net result is sidewall etching, because the etching rate is much higher than the redeposition rate. However, when the angle is greater than 70°, a net redeposition will result.

Fluorine-containing plasma offers a non-toxic and non-corrosive alternative to chlorine-containing plasma. A TiC etching rate of 21 nm/s (1.26 m/min) can be achieved in a high-density F^-containing plasma since TiF_4 (the TiC etching product) is volatile. [4] Al_2O_3 reacts with F to form a mixture of AlF_3 and Al_x O_y F_z [5], these reaction products are not volatile. But the etching of Al_2O_3in F-containing plasmas has been found to be much faster than in an Ar plasma [6] because of the high sputtering yield of AlF_3 compared to that of Al_2O_3 .

Plasmas: $e^- + CF_4 \rightarrow CF_3^+ + F + 2e^-$

Etching: $Al_2O_3/TiC + F^- \rightarrow TiF_{4\ (volatile)} + Al_xO_yF_{z\ (nonvolatile)} + AlF_{3\ (nonvolatile)}$

Sidewall of the MR head after each run of reactive ion etching process show the F- contained redeposition by EDX spectrum as shown in Figure 2.7. This kind of redeposition can be cleaned but the effectiveness of each cleaning approaches are different. In Figure 2.8 (a) redeposition is completely removed and (b) partial removed by cleaning process.

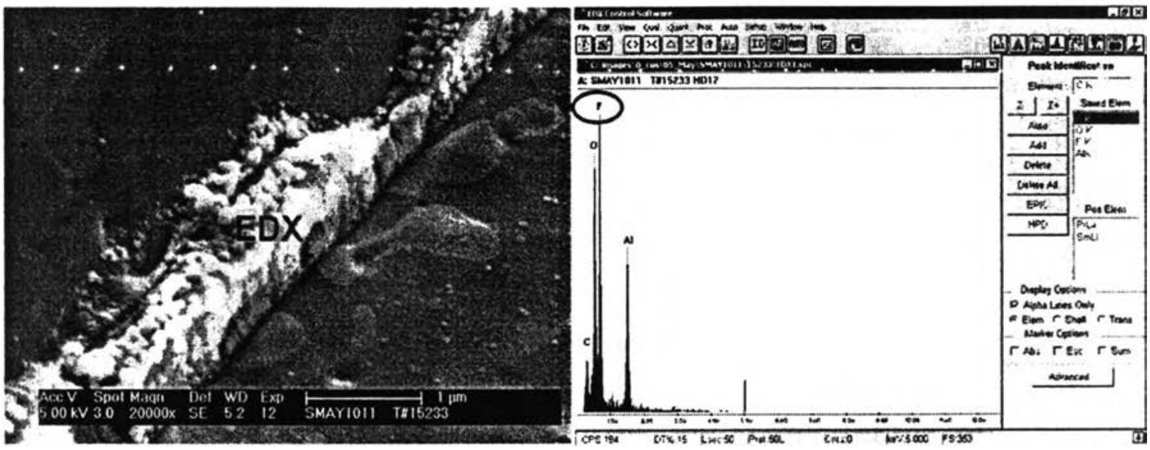

Figure 2.7. Composition of the redeposit is detected by the Energy Dispersive Spectroscopy (EDS). Redeposit is composed mainly of alumina and fluorine with trace amount of carbon possibly from the photoresist residue.

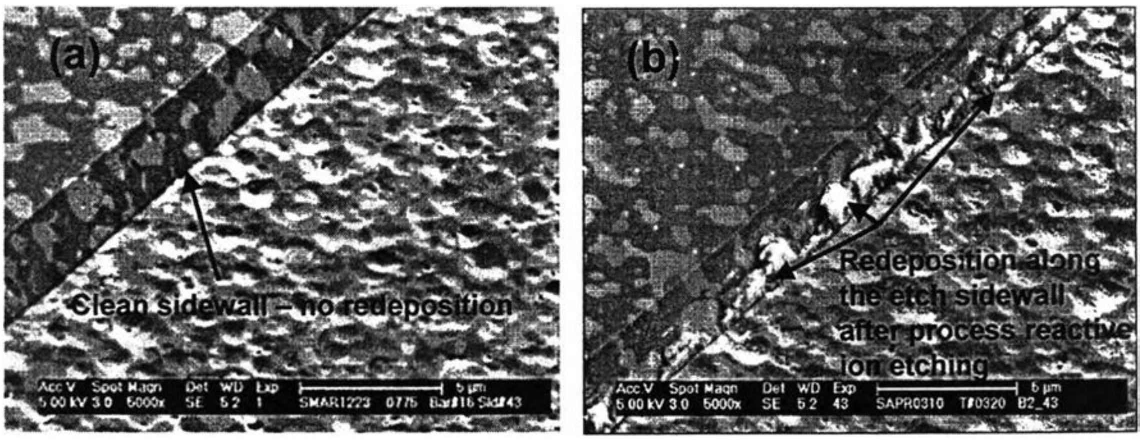

Figure 2.8. Etched sidewall image comparing (a) a clean sidewall; and (b) a sidewall with redeposit after reactive ion etching.

To minimize sidewall redeposition [1], there are 3 processes involved. First is the etching process itself; followed by the design of the photo mask and proper cleaning solution.

- High incident-angle (with respect to the wafer surface normal) etching process can be used. Such an approach results in a more tapered etching profile.

- Low incident-angle process can be used to produce near-vertical sidewalls followed by a high-incident-angle process to remove the redeposition on the sidewalls.
- Redeposition involves rendering the redeposition product water-soluble so that the redeposition can be eliminated by rinsing after etching.
- Propose rounded resist mask (formed by resist reflow bake) to reduce redeposition but etching of rounding mask also produces difficulty in precisely controlling the final dimension.
- Improvement of chemical cleaning process to remove the redeposition on sidewall.

Redeposition is an etch product. AlF_3 is nonvolatile by product that can build up on the sidewall during etch. In general redeposition can be removed post etch. However, where cleaning is not completely effectively, there is a concern that redeposisted material may detach from the slider during drive operation.

2.4. Cleaning Process to Minimize Redeposition on Etched Sidewall

In magnetic head recording field, there are few techniques to apply after etching for remove the redeposit on sidewall. To clean out redeposit on magnetic recording head sidewall, one needs to consider the impact on the electrical performance, the mechanical defect, and corrosion on the device.

The current process used in Western Digital for Femto TuMR product is the Sodium Hydroxide (NaOH) cleaning. As shown in Figure 2.9, the parts will be subjected to dipping and scrubbing in the NaOH solution after it has been etched by the RIE process. Currently employed NaOH cleaning process steps at Western Digital includes rinsing the parts with DI water; followed by immersing the part into 0.02% w/v NaOH solution; then scrubbing in x-y direction; and finally transferring the part to DI rinsing and N_2 blow dry. NaOH will attack to AlF_3 and accelerate the removal by scrubbing. However, the effectiveness of redeposit removal is not 100% under this condition. As shown in Figure 2.10, redeposit can still be seen left on sidewall after cleaning process with varying magnitude.

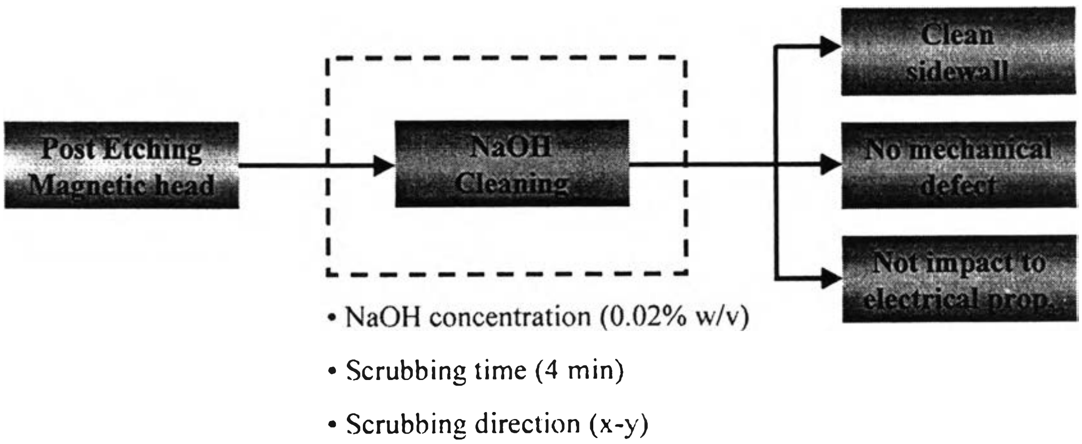

Figure 2.9. The diagram of existing NaOH cleaning to remove redeposition from reactive ion etching process.

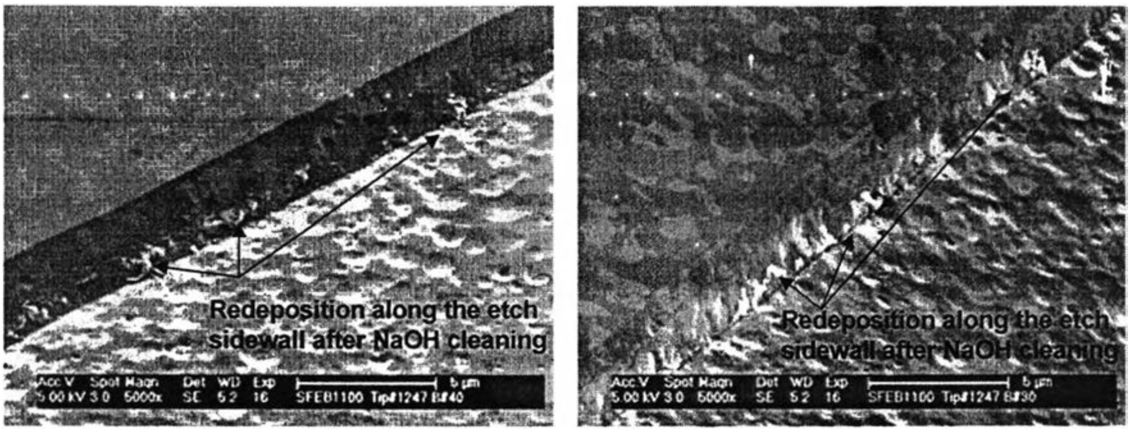

Figure 2.10. Redeposition left on etch sidewall after NaOH cleaning.

Proper chemical and cleaning action are very important to the removal efficiency. The primary role of sodium hydroxide (NaOH) in cleaning will be the generation of hydroxide ions (OH^-). This OH^- ions will be react with the redeposition; while the counter ions (Na^+) are unlikely to play a role in this situation. [15]. However, using NaOH will need a physical/mechanical energy either in the form of scrubbing force or ultrasonic to complete the cleaning action. Therefore, there will be 3 key governing parameters under this circumstance which dictates the cleaning efficiency.

Firstly, the cleaning efficiency will be highly dependent on the consistency of the physical process. In other word, any variations of the energy expended during the physical process – either in the form of scrubbing, sonication, or others – will directly vary the amount of cleaning actions. This leads to the second parameters governing the cleaning efficiency which is the cleanliness of the incoming parts coming from the upstream process. It is very common that etch processes can vary over time and resulting in a varying amount of redeposit and the magnitude in which this redeposit adhere to the etched sidewall. Finally, the third issue involves the re-contamination of the parts in the cleaning process itself. This is especially a common problem associated with the use of poorly circulated cleaning using sonication.

It is to be noted also that, in addition to the cleaning efficiency itself, the challenges is also in minimizing the side effect that might be occurred to the read-write device and also the alumina layer surrounding the read-write elements. There are some chemicals that are capable of fully removing the redeposit. However, most of these chemicals will also the severely attach the read-write element and/or the slider material. Therefore, it is imperative that the study of cleaning process optimization is also accompanied by a study of associated side-effect (i.e. defect generation).