Appendix A

The deflection (ω) of a plate for steady state is obtained by solving

$$D\nabla^4\omega = T\nabla^2\omega + q, \tag{1}$$

where D is the flexural rigidity of the plate, T is residual stress of the plate, and q is the external pressure applied to the plate. For simplicity, a square plate with side length of a is considered. General solutions for equation (1) can be expressed using $\exp(kx)$ where k is wavenumber($k = 2\pi/\lambda$). By replacing ω in equation (1) with $\exp(kx)$, equation (1) becomes

$$Dk^4\omega = Tk^2\omega + q \quad . \tag{2}$$

The next step is to determine whether the deflection of the plate is tension dominant or bending dominant. The means of comparison is given by

$$\frac{Dk^2}{T} >> 1 \qquad \text{bending dominant ,}$$

$$\frac{Dk^2}{T} << 1 \qquad \text{tension dominant.}$$

If the deflection of a plate is bending dominant, equation (1) then becomes

$$D\nabla^4\omega = q. \tag{3}$$

If the deflection is tension dominant, equation (1) becomes

$$T\nabla^2\omega = q. \tag{4}$$

When only the first mode of deflection is of interest, $\lambda = 2a$, and

$$\frac{Dk^2}{T} = \frac{D}{T}\left(\frac{\pi}{a}\right)^2.$$

For example, a composite film stack consisting of two silicon nitride (1700 Å) layers cladding a silicon dioxide layer (4500 Å) has been considered. The Young's moduli of silicon dioxide and silicon nitride are obtained from [1] . The equivalent Young's modulus and residual stress are calculated from equation (3.1)

$$E_{eq} = 204 \text{ GPa} \ , \qquad \sigma_{eq} = 0.3 \text{ GPa} \ .$$

The flexural rigidity D_{eq} of the composite stack is

$$D_{eq} = \frac{E_{eq} \cdot h^3}{12 \cdot (1 - \upsilon^2)} \approx 9.2 \times 10^{-9} N \cdot m \ .$$

The built-in stress T of the composite stack is given by

$$T = \sigma_{eq} \cdot h \approx 240 \ N/m \ .$$

If the length of the square diaphragm is 100 µm, then

$$\frac{Dk^2}{T} \approx 0.04 << 1.$$

Therefore, the deflection of the square diaphragm is tension dominant and approximated with equation (4).

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1. B. Halg, "On a Micro-electro-mechanical novolatile memory cell," *IEEE Trans. Electron Devices*, vol. 37, pp. 2230-2236, 1990.

Appendix B

Photolithography

This photolithography process has been developed for AZ5214E, AZ5209 or equivalent positive photoresists. An aligner, made from HTG, was used which employed direct contact printing. As an exposure light source, mercury lamp was used and the light intensity at 402 nm was 3.2 mW/cm^2. A full description of the photolithography is following as:

- Cleaning a wafer with acetone/methanol/deionized (DI) water and bake the wafer for dehydration at 150 ^oC for 5 min
- Spin adhesion promotor (HMDS) and photoresist on the wafer at 3000 rpm for 30 sec
- Prebake the photoresist at 90 ^oC for 1 min on a hot plate
- Align the wafer with a mask
- Exposure the wafer with the mask for 60 sec
- Develope exposed photoresist with a developer (AZ425) for 1 min
- Flood exposure for 15 sec
- Postbake the developed photoresist at 120 ^oC for 15 min (by convection)

In addition, Image Reversal Photolithography process could be achieved using AZ5214E. With this process the photoresist could be used as a negative photoresist. The process is following as:

- Cleaning and dehydration bake is the same as the above
- Preparation of photoresist is also the same as the above
- Prebake and exposure steps are the same as the above
- After exposing the wafer, bake the exposed wafer at 100 ^{o}C for 1 min. This step is very critical because additional heating makes the exposed phtoresist not be soluble in developer (AZ425).
- Expose the wafer without a mask for 2 min
- Develope the wafer with the developer for 1 min
- Flood exposure and postbake steps are the same as the above.

Appendix C

Wafer Cleaning Techniques

- Piranha Cleaning

Piranha cleaning is very effective to remove organic contaminants , such as photoresist residue. The cleaning solution was made of sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) (2:1 by volume). Due to exothermic chemical reaction, the temperature of the mixed solution increases. Wait for 5 minutes to stabilize the temperature. Wafers were dipped into the solution for 8 minutes. Upon removal from the solution, the wafers were rinsed in DI water and spin-dried.

- RCA Cleaning

RCA cleaning removes first organic contamination and then inorganic ions and light metal ions, such as potassium and sodium, by using two solutions in sequence. For organic contaminants and certain metal ions, such as silver and cobalt, a mixture of water, ammonium hydroxide (NH_4OH) and hydrogen peroxide (H_2O_2) (5:1:1 by volume) was prepared and heated to 70^oC- 80^oC. Ammonia is effective in removing metal ions by forming compex -amine with them. The wafers were submerged in the solution for 10 minutes with the temperature maintained below 80^oC. Note that NH_4OH in the absence of H_2O_2 will etch silicon wafer and the depletion of H_2O_2 occurs above 80^oC at which H_2O_2 is rapidly decomposed.

For inorganic and metal ions, a mixture of water, HCl and H_2O_2 (5:1:1 by volume) was prepared and heated to $70\,^oC$- 80^oC. After the first cleaning, followed by DI water rinse, the wafers were submerged in the solution for 10 minutes. Finally, the wafer was rinsed in DI water and spin-dried.