CHAPTER 4

HIGH REFLECTANCE OPTICAL THIN FILM GRATING LIGHT VALVE

4.1 EFFICIENCY OF GLV

The significant impact of MOEMS in display technology has resulted in a well controlled diffractive optical display device called Grating Light Valve (GLV). This is a programmable diffraction phase grating that operates on the electrostatic deflection of micro beams formed of moving parts on the surface of a silicon chip. Each GLV element consists of typically six dual-supported parallel ribbons formed of silicon nitride (Si_3N_4) and coated with a thin layer of aluminium at the top. This section presents an approach to achieve high reflective Grating Light Valve. In visible spectral regions, a dielectric multilayer can be used to enhance the reflectivity based on the optical interference effect in Grating Light Valve. In this analysis aluminium is used as a metal sub-layer. By coating a dielectric stack over this layer will further enhance the reflectivity of the device over a wide range of wavelengths. Here, the stack comprises of low and a high reflective layer of low and high refractive index materials Silicon dioxide (SiO_2) and Hafnium oxide (HfO_2) respectively.

The optical efficiency of the GLV device is the product of diffraction efficiency, fill factor efficiency and the reflectivity of the top layer. The overall device efficiency is about 70%, corresponding to an insertion loss of about 1.5 dB. Zeroth order and first order diffraction efficiencies are (Jahja I. Trisnadi 2004)

$$\eta_0 = R_r \mu^2 cos^2\left(\frac{2\pi\delta}{\lambda}\right) + R_g (1-\mu)^2 + 2\sqrt{R_r R_g}\,\mu(1-\mu) cos\left(\frac{2\pi\delta}{\lambda}\right) cos\left(\frac{2\pi(\delta - h)}{\lambda}\right) \tag{4.1}$$

$$\eta_{\pm 1} = \frac{4}{\pi^2} R_r sin^2\left(\frac{\mu\pi}{2}\right) sin^2\left(\frac{2\pi\delta}{\lambda}\right) \tag{4.2}$$

where 'R_r' is the ribbon reflectivity, 'R_g' is the gap reflectivity, 'δ' is the deflection depth of the ribbon, 'λ' is the wavelength of the input light signal, 'h' is the initial gap between the top and bottom electrode, 'μ' is the fill factor defined as w_r **/(**w_r+w_g**),** w_r and w_g are ribbon width and ribbon gap respectively. Among the structural parameters, the gap between the ribbons is defined by the minimum feature characteristics of the lithographic tools used to pattern the ribbon.

Reflectivity (R_r) of the top layer depends on the type of material selected. The high reflectance is one of the preconditions to achieve effective operations in the application of projection displays. In GLV aluminium is used as a top layer, which has about 90% reflectivity. When the GLV device is finished and tested, a clear glass lid is fixed above the ribbon area sealing in a dry nitrogen environment for pressure equalization and to prevent oxidation. However, aluminium oxide is formed on the fresh surface of deposited aluminium, which reduces the reflectance. The common solution is to deposit a transparent fluoride coating as a capping layer. However, due to its intrinsic property, aluminium can only provide 90% reflectivity.

4.2 HIGH REFLECTIVE OPTICAL COATINGS

Eiichi Tamaki (2004) explained the improvement of the spectral reflectance, using optimized multi-layer structure substrate in his paper. High reflector’s primary function is to increase the reflectivity of a surface and in most cases, move or steer the light to another location in an optical system. Metal coatings, such as Protected Aluminium, Protected Silver or Protected Gold provide reflectance over an extremely broad spectral range. These coatings are protected by a thin layer of dielectric material in order to make them durable. It is also possible to enhance the performance of metal coatings by adding several dielectric layers over the metal coating.

In the structural design of the enhancement layers, the low index layer is closest to the metal and the high index layer is closest to the medium. The Figure 4.1 shows an enhanced aluminium with high index of 2.40 and a low index of 1.48 materials. Enhancing the reflectivity of a metal layer will boost the reflectivity of the metal layer around the desired wavelength.

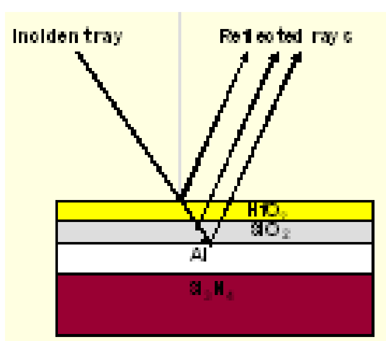

Figure 4.1 Multilayer reflection

Figure 4.2 represents the reflectivity of bare aluminium layer and the enhanced aluminium with one, two and three stacks comprised of higher and lower refractive index materials alternatively. The enhanced aluminium layer has high reflectivity than the bare aluminium layer. Reflectivity increases further with increase in number of stacks.

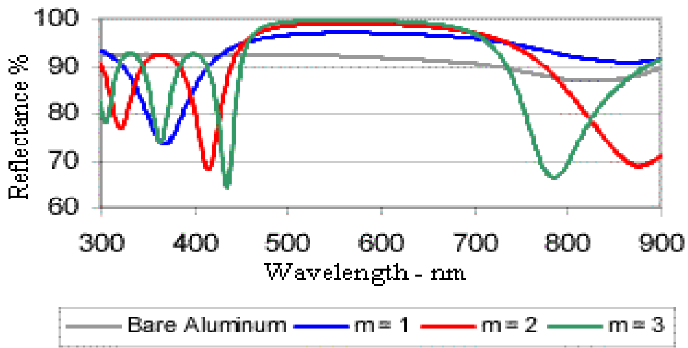

Figure 4.2 Reflectivity of bare Al and Enhanced Al for m=1,2,3

4.3 DEVICE SIMULATION

This section presents simulation approaches using MEMSCAD to achieve high reflective Grating Light Valve. In visible spectral regions, a dielectric multilayer can be used to enhance the reflectivity based on the optical interference effect in Grating Light Valve. The most important factor in producing films with high reflectance is found to be extremely fast evaporation. Coating a dielectric stack over this aluminium layer will further enhance the reflectivity of the device over a wide range of wavelengths. By choosing materials of the stack with appropriate refractive indices, the various reflected wavefronts can be made to interfere constructively in order to produce a highly efficient reflector. The stack comprises of low and a high reflective layer of low and high refractive index materials SiO_2 and HfO_2 respectively.

Figure 4.3 describes the cross sectional view of the proposed Grating Light Valve ribbon. Hafnium dioxide (HfO_2) is a high-index, low-absorption material usable for coatings in the near-UV (below 300 nm) to IR (~10 µm) regions. Hafnium dioxide films are almost absorption-free over the range below 300 nm to at least 10 µm. Adhesion is excellent to glass, most other oxides and to metals such as aluminium and silver. The films generally grow with a crystalline microstructure. Under some evaporation conditions, such as low energy evaporation, low substrate temperature or excessive background pressure, the films grow with low packing density and can exhibit index changes when vented to moist air. Some amount of index inhomogeneity can appear with increasing layer thickness and with layer number as the material is consumed. In this analysis the layer thickness is very small and so the inhomogeneity is not a limiting factor. Melting point is 2812°c and crystal density is 9.68 g/cc. Since the index below wavelengths 300 nm is nearer to 2, Hafnium dioxide can be combined in multi-layers with silicon dioxide (n=1.48) for UV laser applications. Hard, scratch-free, dense and adherent coatings can be deposited on relatively low temperature substrates. Its abrasion resistance provides protection of metal mirrors.

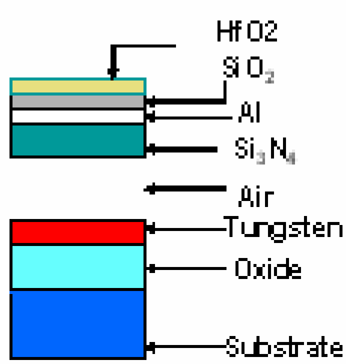

Figure 4.3 Cross section of proposed GLV ribbon

The peak reflectance value is dependent upon the ratio of the refractive indexes of the two materials, as well as the number of paired layers. The width of the reflectance curve (as a function of wavelength) is also determined by the films' refractive index ratio. The larger the ratio is, the wider the high-reflectance region will be. Over limited wavelength intervals, the reflectance of a dielectric coating can easily be made to exceed the highest reflectance of a metallic coating. The peak reflectance can be increased by adding more layers, or by using materials with a higher refractive index ratio. Amplitude reflectivity at a single interface is given by

$$\frac{(1-p)}{(1+p)},$$

where, $$P=\left(\frac{n_H}{n_L}\right)^{N-1}\times\frac{n_{H^2}}{n_S}$$

where n_S is the index of the substrate and n_H and n_L are the indices of the high- and low-index layers. 'N' is the total number of layers in the stack. The design procedure for a broadband reflection coating should now be apparent. Two design techniques are used. The most obvious approach is to use two quarter-wave stacks with their maximum reflectance wavelengths separated on either side of the desired wavelength. This type of coating, however, tends to be too thick and often has poor scattering characteristics. This basic design is very useful for dichroic high reflectors, where the peak reflectances of two stacks are at different wavelengths. A more elegant approach to broadband dielectric coatings involves using a single modified quarter-wave stack in which the layers will not have the same optical thickness. Instead, they are graded between the quarter-wave thicknesses for two wavelengths at either end of the intended broadband performance region. The optical thicknesses of the individual layers are usually chosen to follow a simple arithmetic or geometric progression. By using designs of this type, multilayer, broadband coatings with reflectance in excess of 99 percent over several hundred nanometers are possible. Multilayer broadband coatings are available with high-reflectance regions spanning almost the entire visible spectrum. The Figure 4.4 represents software mask layout of the proposed structure.

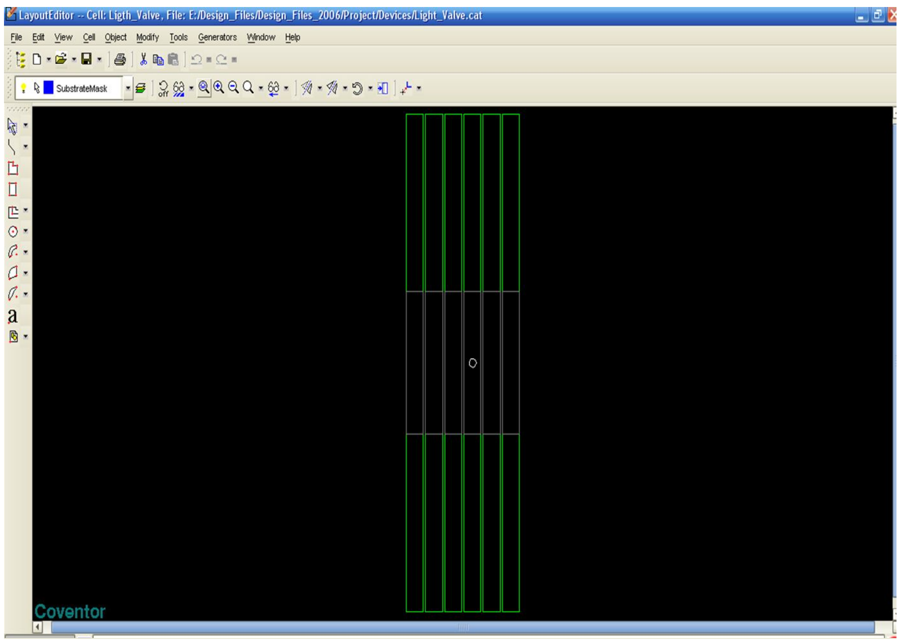

Figure 4.4 Mask layout of proposed GLV structure

The solid model of the mask layout arrived using CoventorWare is shown in the Figure 4.5. In this solid model, on the top layer (Aluminium) a stack comprising of SiO_2 and HfO_2 is added. SiO_2 and HfO_2 are low and high refractive index materials respectively.

Displacements of active ribbon for various control voltages are measured using the CoventorWare and it is plotted in Figure 4.6 and tabulated in Table 4.1.

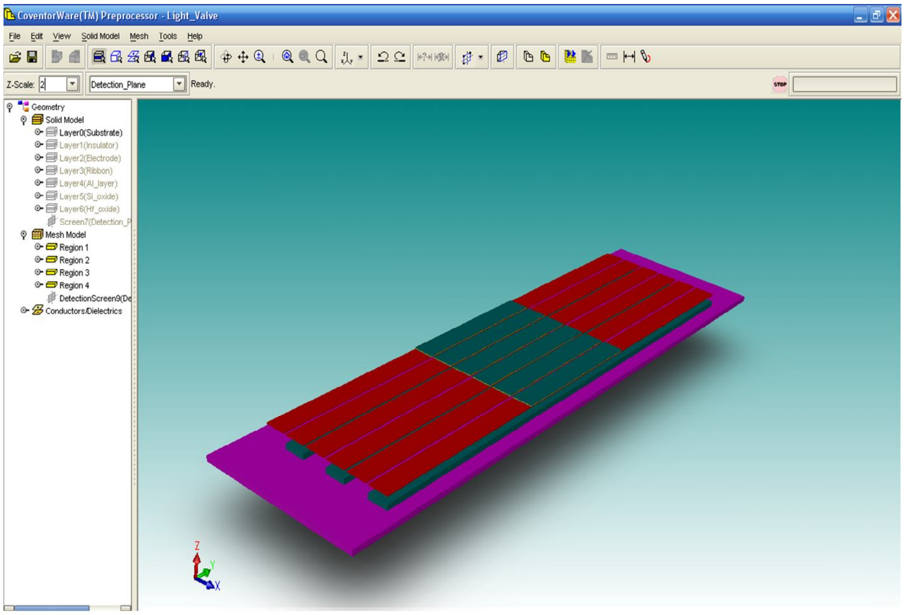

Figure 4.5 Solid model of proposed GLV structure

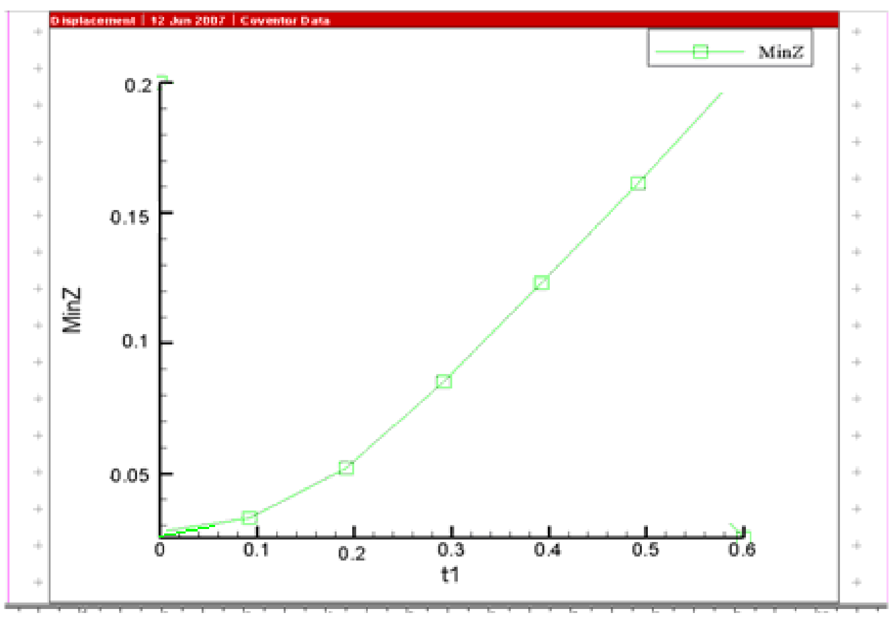

Figure 4.6 Ribbon displacement of proposed GLV

Table 4.1 Displacement analysis summary

Summary

	t1	Iterations	Status	Displacement	Displacement_Change
step_1	0	2	converged	0	0
step_2	1.0E-01	2	converged	5.698392E-03	5.017035E-06
step_3	2.0E-01	2	converged	2.489762E-02	2.448168E-04
step_4	3.0E-01	2	converged	5.781716E-02	1.266528E-03
step_5	4.0E-01	2	converged	9.572316E-02	2.170273E-03
step_6	5.0E-01	2	converged	1.342162E-01	2.925801E-03
step_7	6.0E-01	2	converged	1.745166E-01	4.045402E-03

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The movement of active ribbons in a GLV pixel is shown in Figure 4.7.

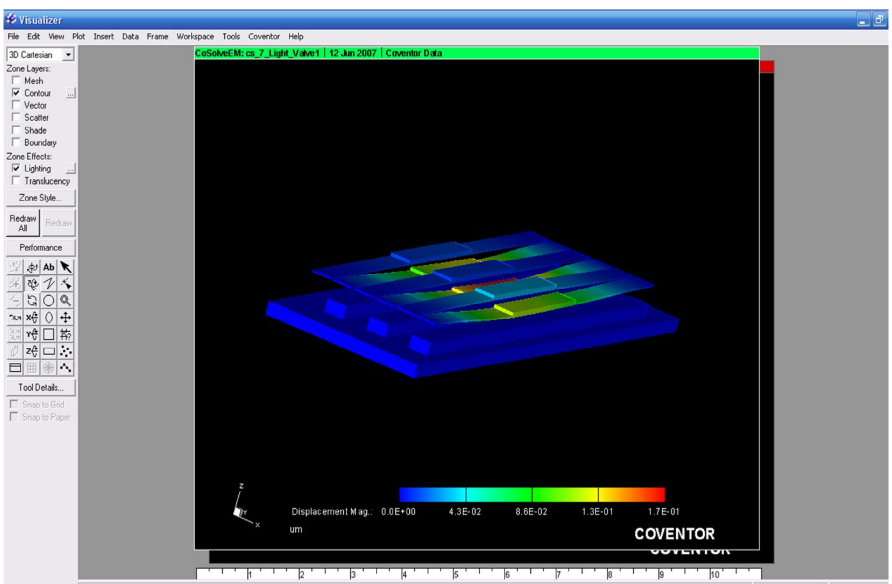

Figure 4.7 Proposed GLV structure's displacement simulation view

Table 4.2 gives the summary of capacitance of the proposed GLV structure.

Table 4.2 Summary of capacitance of the proposed structure

Capacitance

	t1	C_Conductor_0_Conductor_0	C_Conductor_0_Conductor_1	C_Conductor_1_Conductor_1	C_Conductor_0_Conductor_2	C_Conductor_1_Conductor_2	C_Conductor_2_Conductor_2
step_1	0	9.795515E-03	-2.776549E-04	6.617419E-01	-1.018083E-03	-9.436436E-03	3.243434E-01
step_2	1.0E-01	9.81807E-03	-2.842304E-04	6.642043E-01	-1.024044E-03	-9.353089E-03	3.328261E-01
step_3	2.0E-01	9.89381E-03	-3.07557E-04	6.727569E-01	-1.048651E-03	-8.979294E-03	3.592778E-01
step_4	3.0E-01	1.003997E-02	-3.565899E-04	6.910273E-01	-1.132065E-03	-8.34632E-03	3.98263E-01
step_5	4.0E-01	1.024909E-02	-4.367503E-04	7.238972E-01	-1.33026E-03	-8.000142E-03	4.354269E-01
step_6	5.0E-01	1.049551E-02	-5.474656E-04	7.788958E-01	-1.660945E-03	-7.871752E-03	4.675423E-01
step_7	6.0E-01	1.078311E-02	-6.881537E-04	8.849425E-01	-2.193134E-03	-7.93229E-03	4.974861E-01

OK

4.4 DISCUSSION

The damage threshold for this structured stack is found to be 0.4 J/cm^2 ±10%, 10 nano sec pulse (33 mw/cm^2) at 532 nm and 0.3 J/cm^2 ±10%, 20-n sec pulse (12mw/cm^2) at 1064 nm. Due to the addition of stack to improve the reflectivity, the pull in voltage of the ribbon is slightly increased. The total thickness of the system including dielectric stack is 100 nm. The aluminium sub-layer is carefully designed and sandwiched between dielectric stack and Si_3N_4. Silicon Nitride layer provides a spring like restoration force that counter balances the electrostatic actuation force and it also provides stiffness and stress balance so that ribbon remains flat across its width. This force is further increased a little by a dielectric stack on the ribbon. The durable enhancing multilayer produces a peak reflectance of 96% with an average of 94% across the visible spectrum. Figure 4.8 shows the simulation result of reflection at 0V, 0.5V and 1.0volts from GLV ribbon without adding dielectric stack on aluminium top layer. At the same time Figure 4.9 shows

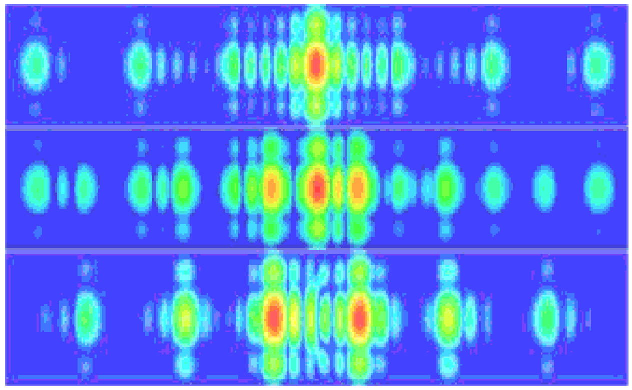

Figure 4.8 Reflection from GLV ribbon without dielectric stack at 0 V, 0.5 V and 1.0 V

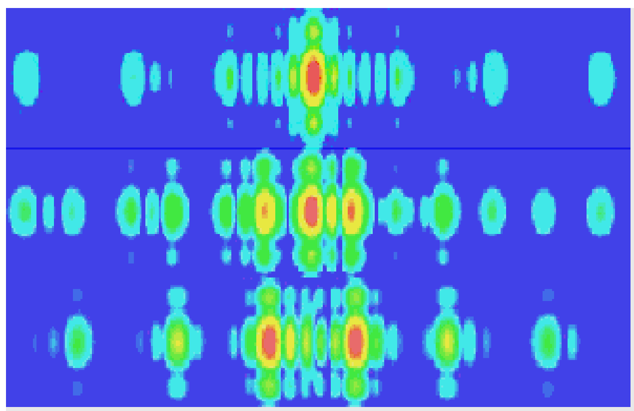

Figure 4.9 Reflection from GLV ribbon with dielectric stack at 0 V, 0.5 V and 1.0 V

the simulation result of reflection at 0V, 0.5V and 1.0volts from GLV ribbon with dielectric stack on aluminium top layer. These results show that the received light signal clarity is increased by adding a stack comprised of high and low refractive index layer. The reflectance of enhanced aluminium peaks between 530 nm and 580 nm and is high from 400 nm to 850 nm. As a result aluminium with dielectric layer can provide reflectance of 95% for wide wavelength ranges with low thickness. The effect is found to be much better than the conventional bare aluminium coating. The dielectric layer prevents oxidation of the aluminium surface and provides abrasion resistance.