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13. ABSTRACT (Maximum 200 words)

During the period covered by this report, we have successfully overcome several technical challenges for the device fabrication and made solid progress heading toward a functional optical modulator of 635 nm working wavelength. This is the wavelength of the commercially available DVD lasers.

The key challenge for us is the insufficient thickness control in spin-coating in the university fabrication laboratory like ours. As will be shown in the report, the variation in the film thickness is significantly larger than the value that is routinely achievable in manufacturing facilities, which is what is required for matching of the cavity mode with the laser wavelength. We have also fabricated several prototypes of devices with the absorption peak narrowly missed the 635 nm working wavelength. All of these suggest that we are at the eve of making a well functional optical modulator.

Another key element of the program is the education of under represented students. Mr. Seife Woldeeyesus, who is an undergraduate student at UCLA participated actively in the program. He has mastered the technique of device processing especially sputter deposition. Moreover, his professional maturity and interest in engineering have progressed significantly.

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Abstract

During the period covered by this report, we have successfully overcome several technical challenges for the device fabrication and made solid progress heading toward a functional optical modulator of 635 nm working wavelength. This is the wavelength of the commercially available DVD lasers.

We explored the parameter space of the RF sputtering deposition and spin-coating process. Low absorption, high reflective quarter-wave stacks (QWS) which serves as the mirrors for the 635 nm resonant cavity have been successfully fabricated. Acceptable thickness control for the electronic-absorption layer (quantum dots layer) by spin-coating is also achieved by pre-surface-preparation and step-annealing.

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Highlights of Research Accomplishment

Deposition of High Reflective Quarter Wave Stack

To make high reflective top and bottom mirror, we use radio-frequency magnetron sputtering to deposit a four-unit quarter wave stack composed of alternating layers of SiO_2 and TiO_2. The challenges are, to get a high reflective mirror (reflectance > 90%), we need to minimize the absorption coefficient of the two materials and precisely control the thickness of each layer.

To minimize the absorption coefficient, the mole ratio of Si : O and Ti : O should be maintained to be 1 : 2 in both SiO_2 and TiO_2 layers, this is because the excess amounts of any element would lead to increased absorption. Although we use SiO_2 and TiO_2 sputtering target, the composition of the film deposited are still SiO_x and $TiO_{x'}$, where x and x' are values less than 2. This is because both Si and Ti have a larger atomic mass and thus have a higher sticking coefficient over oxygen, especially for Ti. We have successfully optimized the film stoichiometry by setting the ratio of Ar:O to be 21:15 in our Perkin-Elmer 2400 Series Sputtering Systems.

To precisely control the layer thickness, we explored the parameter space of the sputtering deposition. The radio-frequency power is set to be 750W for SiO_2 and 1000W for TiO_2 to get the deposition rate which optimized the film quality. A series of calibration runs are completed to determine the recipe of substrate table position, sputtering time, and pre-sputtering time.

Using the recipe we developed, quarter wave stacks with reflective coefficient above 90% at the 635nm working wavelength can now be routinely fabricated. (See Figure.1)

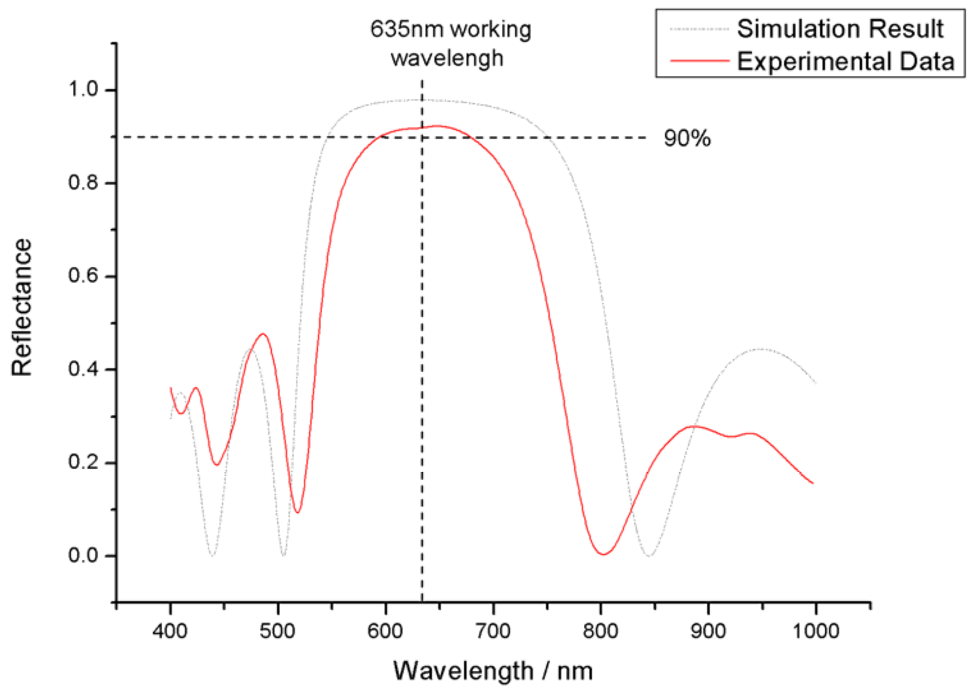

Figure.1 Refection spectrum of 4-unit quarter wave stack

Thickness Control of Spin-Coating Deposition

Compared to the thickness of the layers in the quarter wave stack, the thickness of the cavity layer (quantum dots optical absorbing layer) is more critical for the function of the modulator, since it directly determined the position of the absorption peak. The challenge is how to precisely control the thickness of the spin-coated layer while obtaining an acceptable repeatability. A lot of work has been done for this purpose, including pre-surface-preparation and step-annealing.

We use Spin-On-Glass (SOG) as the matrix material for the quantum dots. The solution for spin-coating is mixed by SOG and quantum dots solution (toluene solvent) with a 1:1 volume ratio. It turns out that the precise control of the film thickness from spin-coating process is fairly challenging for a university laboratory. The film thickness is affected by many factors with the solvent evaporation rate being the most sensitive parameter. We have employed two approaches to combat this problem. We have modified the spin-coater to lessen the fast evaporation of the solvent, and we have also employed stepped-annealing as used by the industry that is consisted of annealing at 80℃, 150℃, 250℃ for 1 minute each, to improve the reproducibility in film thickness.

With all these measures taken, we managed to narrow down the thickness value spread to within the device tolerance range (± 5nm) in some cases and outside for others. (See Figure. 2)

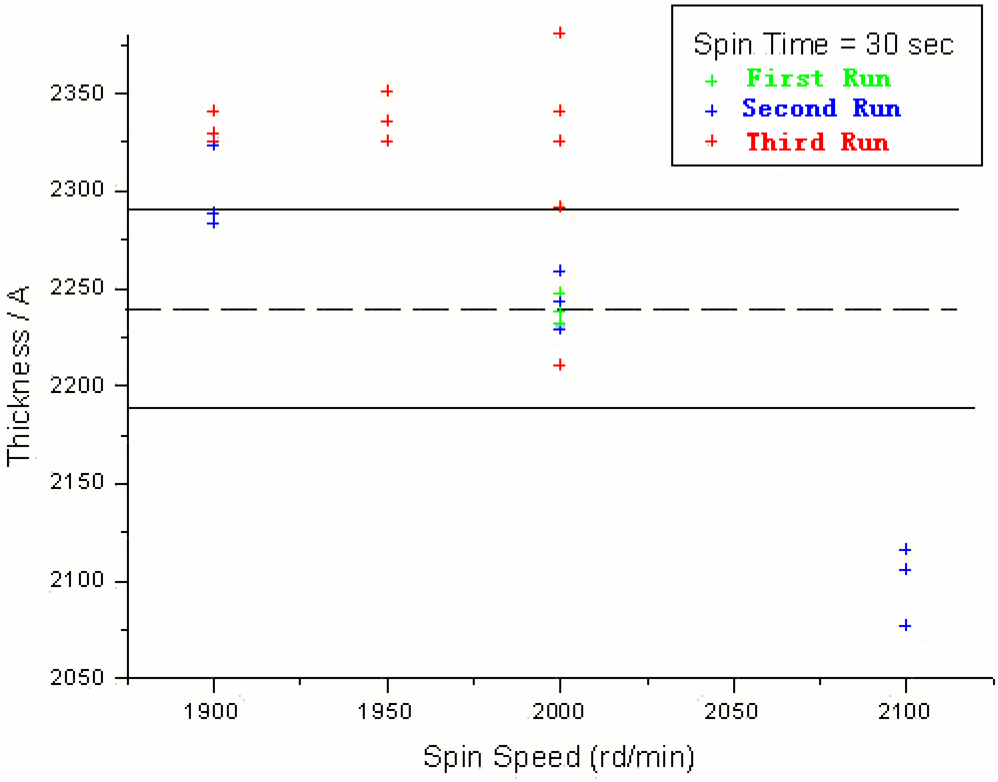

Figure.2 Thickness distribution of the spin-coated layer as a function of the spin speed

The dash horizontal line shows the desired thickness and the range between the two solid horizontal line represents the thickness tolerance

Measurement of completed device

So far we have fabrication several completed devices, some of which have the absorption peak narrowly missed the position of the working wavelength (See Figure.3). Although we have no succeeded in fabricating a device with precise matching between the cavity mode and the working wavelength, it can be said that we are close to that goal.

For the near future, we plan to continue working on narrowing down the thickness variability in spin-coating for the purpose of obtaining a fully functional device.

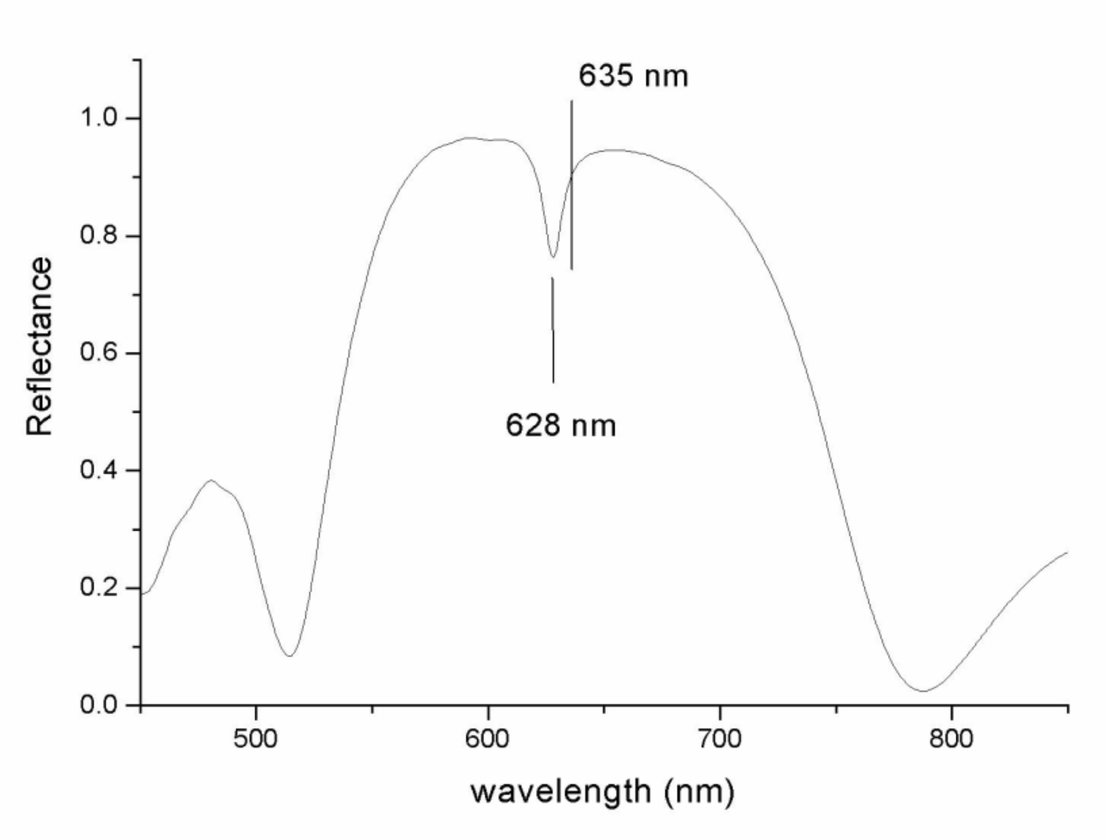

Figure.3 Reflection spectrum of a completed device