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# 자기광학 공간 광 변조기

# Magneto-Optic Spatial Light Modulator

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This paper briefly reviews magneto-optic spatial light modulators (MOSLMs) developed so far and discusses the design concepts, issues concerning its fabrication, and performances of a new MOSLM based on one-dimensional magnetophotonic crystal (1D-MPC).

Spatial light modulators (SLMs) are key components for optical correlators, optical computers, holographic data storage, and cross bar switches of optical fiber communication. Traditional SLMs constructed from photographic film were used as early as the 1950s by the pioneers in the field of optical pattern recognition and parallel signal processing.[1] Various types of reusable modern SLMs with two-dimensional array of pixels have been intensively developed over the past two decades.[2] Of these, magneto-optic spatial light modulators (MOSLMs) have advantages of high switching speed, robustness, nonvolatility, and radioactive resistance. The high switching speed results from the fact that MOSLMs switch light on and off via switching the magnetization direction of the pixels, which can be reversed on the order of 1 ns.[3] MOSLMs are also robust and nonvolatile because they are basically solid state and the pixels do not spontaneously demagnetized even after the power is off.

The first MOSLM was the magneto-optic-photoconductor sandwich (MOPS) developed by Krumme et al. at Philipps three decades ago.[4] The MOPS used the magnetic garnet film grown on a nonmagnetic substrate. It consisted of an array of square magnetic garnet islands or pixels magnetically separated. The pixels were optically addressed by heating a pixel to be switched using a laser beam under an external bias field applied across the whole array. Since the pixels were thermally switched, the switching speed was rather slow. Secondly, because of the lack of light deflectors with large deflection angle for the optical addressing, the MOPS was limited in application.

Another type of MOSLM was the magneto-optic controlled transparency (MOCT) developed in the Soviet Union two decade ago.[5] The MOCT was also based on the garnet film but had uniquely designed pixels. The pixels were hexagonally structured by removing the film from all sides except one. To switch a pixel, the magnetic domain wall of the unpixelated area was pushed into the pixel through the side from which the film was not removed. Since this device did not require that a domain wall be nucleated, but simply moved about, the device had the advantage of a low drive current. However, it suffered from poor stability of the written information.

The first commercialized MOSLM was the Litton iron garnet H (magnetically) triggered magneto-optical device (LIGHT-MOD) developed by Ross et al. at Litton two decades ago.[6] Like MOPS, the LIGHT-MOD also consisted of an array of square garnet pixels but the pixels were electrically addressed using X-Y matrix drive conductors. It thus had high switching speed and high stability of the written information. But it needed a rather high drive current to produce a magnetic field high enough to nucleate the domain wall. It operated in transmission mode and consisted of large gaps between the pixels in order to provide space for the X-Y drive conductors which were placed in the gaps.

Since the inception of the LIGHT-MOD there have been significant advances in device fabrication techniques such as electron beam lithography, ion beam etching, and plasma etching as well as components such as laser diodes, CCD detectors, BiCMOS drive electronics, and high density interconnected multichip module packaging. Utilizing the advances in processing and supporting technology the advanced version of the LIGHT-MOD, the reflected mode MOSLM (R-MOSLM), has been developed by Ross et al. at Litton a decade ago.[7] R-MOSLM also consisted of an array of square garnet pixels and pixels were electrically addressed using X-Y matrix drive conductors but operated in reflected mode by introducing the X-Y matrix metal layers on top of the pixellated garnet surfaces which served as both drive conductors and reflective mirrors. The R-MOSLM took the advantage of the nonreciprocity of the Faraday effect, used thinner garnet film, and had a high resolution with narrower pixel gaps. But It still needed a rather high drive current to produce a magnetic field high enough to nucleate the domain wall.

The MOSLMs developed so far required thick garnet film to obtain the maximum contrast ratio between the dark and light pixels. The optimum film thicknesses in the transmission and reflected modes were roughly 20 um and 10 um, respectively, for the light wavelength of currently available red semiconductor lasers and for the best available magneto-optic garnets. However, from a device fabrication standpoint and a drive current standpoint the thinner the film the higher the resolution and the lower drive current that can be achieved.

A new reflected mode MOSLM based on the one-dimensional magneto photonic crysal (1DMPC-MOSLM) have developed by Cho et al. at Gyeongsang National University in 2000. The 1DMPC-MOSLM is consisted of a thin garnet film of several 100 nm sandwiched by two multilayers of two kinds of alternately stacked dielectric layers. The 1DMPC-MOSLM exploits the large Faraday rotation and transmittance of the locallized mode due to the thin garnet defect layer in the photonic band gap produced by the two dielectric multilayers.[8]

Figures 1 and 2 are schematic representations of the structure of the 1DMPC-MOSLM. The 1DMPC-MOSLM comprises two alternatively

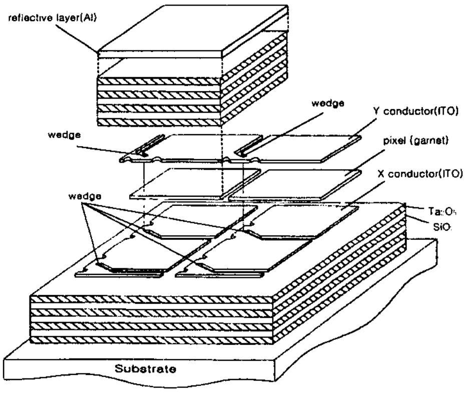

**Fig.1.** Structure of reflective one-dimensional magnetophotonic crystal spatial light modulator

stacked dielectric layers that sandwich a magnetic layer, (glass substrate) /$(T/S)^4$ (T/I)/G /(I/T) $(S/T)^4$/Al, where T, S, I, and G are $Ta_2O_5$ (79 nm), $SiO_2$ (108 nm), ITO (116 nm), and Bi-substituted iron garnet (300 nm).

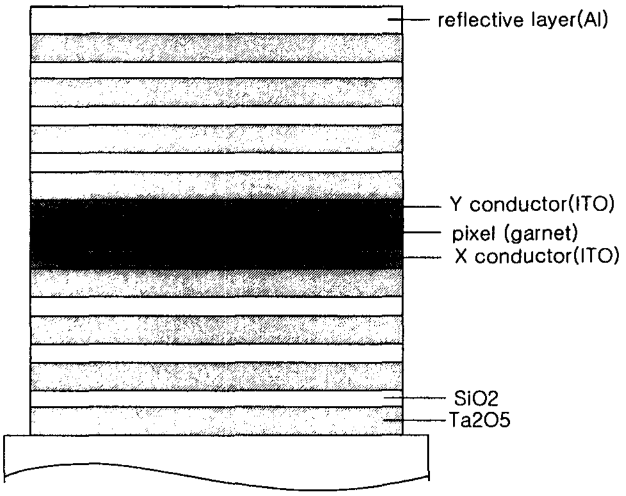

**Fig.2** Cross section of reflective magnetophotonic crystal spatial light modulator

The bottom dielectric multulayer, $(T/S)^4T$, was first alternatively sputter-deposited on the glass substrate. The bottom ITO, amorphous garnet, and top ITO layers were then deposited and structured as X drive conductors, pixels and Y drive conductors, respectively. The X-Y matrix

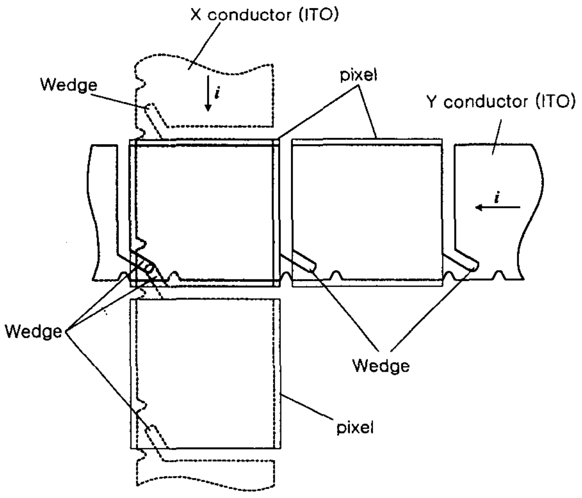

**Fig.3** Top view showing how X conductor, pixel, and Y conductor overlap

drive conductors were designed by 3D electromagnetic field computer simulation to have a wedge (Figs 1 and 2) on each pixel so that they were able to produce strong magnetic field where the wedges were crossed (Fig.2, insert) when current was flowed through them. The number of pixels was 16x16=256. The pixel was 50x50 or 100x100 micrometer square wide and pixel gap was 5 micrometer wide. The wafer was then annealed at 750 degree C for 10 min in an electrical furnace to crystallize the garnet layer. The refractive indices of both of ITO layers after being annealed were close to that of the $SiO_2$ layer. The top dielectric multilayer, $(S/T)^4T$ and Al reflective layer were then deposited and structured to open bonding pads and to cover pixels, respectively. Finally the wafer was passivated, diced and wire bonded on an IC package. A bias coil was attached on the IC package. The advantage of using the one-dimensional magnetophotonic crystal was that it gave high Faraday rotation and transmittance even when the magnetic layer was as thin as several 100 nm. It also allowed us to effectively apply magnetic field to the thin pixels. Combination of this and the drive conductors with wedges resulted a factor of 10 times higher pixel switching sensitivity or lower drive current, compared to the conventional modulator whose major drawback was the high drive current. The 1DMPC-MOSLM had the advantages of high speed, high resolution, low drive current, high integrity with drive circuits, low cost, robustness, and nonvalitility.

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