Surface Plasmon Tunable Color Filter and Projection Display

Yu Wang

Jet Propulsion Laboratory
Calfornia institute of Technology, Pasadena, CA 91009

A novel projection display, based on a new phenomenon of voltage-induced color-selective absorption with surface plasmons, are able to generate bright image on a large screen with high efficiency. In addition, neither color filters nor phosphors are needed to generate the color. With the incident beam of $\pm 7°$ half cone angle, the color purity of this device can be as good as the CRT displays, and the contrast ratio can reach over 200:1. System analysis shows that, for a color sequential single panel 1. 8“ surface plasmon projector, the luminous efficiency can reach 3 Lumens/Watt, and for a 1.8” surface plasmon "smart card” projector, the luminous efficiency can reach over 10 Lumens/Watt.

1. introduction

The market of projection display has been growing rapidly in recent years. Though the CRT projectors still leading the way, many flat panel projector models have been introduced. While the brightness and efficiency are still big concerns, the LCD light valve and DMD suffers with low manufacture yields and complex structures, which keep the prices high.

Here I introduce the surface plasmon (SP) projection displays, which are based on a new phenomenon of voltage-induced color-selective absorption with surface plasmons[1], is able to achieve high brightness and high efficiency. In addition, this device can generate the colors without color filters. The optical system is much simpler than the current projectors, which can reduce the size and manufacturing cost.

It is well know that, for prism coupling, SP waves can be generated at a metal/dielectric interface. At this SP resonance, the reflected light vanishes -- attenuated total reflection (ATR)[2]. This resonance depends on the dielectric constants of both the metal and the dielectric. When a voltage is used to change the dielectric constant of the dielectric, the reflected light can be modulated[3-5]. Because of their big birefringence, liquid crystals are among the best mater-ials for surface plasmon light modulator. A contrast ratio over 100 and spectral resolution better than 10 lines/mm had been reported for SP light modulator using laser beam[6,7].

lfa white light is used instead of the laser beam, then only these photons in SP resonance range will be absorbed, and for those photons out of the resonance will be totally reflected, which means the reflected light becomes colored. This is so called SP color selective absorption. If a voltage is used to change the index of the liquid crystal, then the SP resonance will change, and the reflected light will show the change of the complementary color. Depends on the metal film used, the SP resonance could cover just 1/3 of the visible spectrum, which can be used for a tunable color filter, or cover all of the visible spectrum, which can be used as a light modulator.

3. SP tunable color filter

The structure of SP tunable color filter is shown in Fig. 1, This tunable color filter can replace the color wheel used in other projection devices. The incident p-polarized white light is reflected three times by Unit- 1, Unit-2 and Unit-3 to provide the sequential primary colors. initially, when the applied voltages arc zero, Unit-1 is set at SP resonance, of red, Unit-2. is set at SP resonance of green, and Unit-3 is set at the SP resonance of blue. All of the visible lights arc absorbed, and there is no outgoing light. lfa voltage is added on Unit-1, then the red color is off SP resonance, the final outgoing light is red. If a voltage is added on Unit-2 instead, then the green color is off S1' resonance, the final outgoing light is green. Same if a voltage is added on Unit-3 instead, then the blue color is off S1' resonance, the final outgoing light is blue. By turning the voltage on these three units on and off sequentially, we can generate the sequential primary colors.

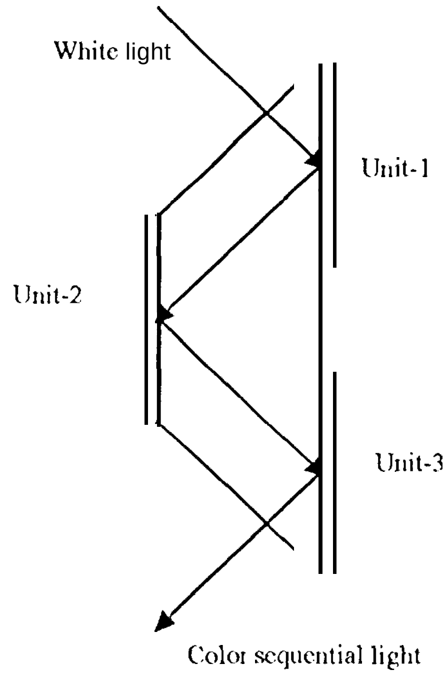

Fig. 1. Surface plasmon tunable color filter. The sequential primary colors are generated by color subtraction.

A theoretical calculation of three absorption curves at each interface arc shown in Fig. 2. Here the metal films arc multiple layer films to provide optimum spectrum range. At a given time, only one absorption curve is being pushed off SP resonance, and the outgoing light show the corresponding color. Theoretical calculation indicates that for an incident beam dive~-gene.e of ±6.7° half cone angle the excellent colors can be generated. The color purities of the primary colors arc shown in Fig. 3. as the heavy solid line, we can see the color purit y is very close to 27" CRT display (the light line).

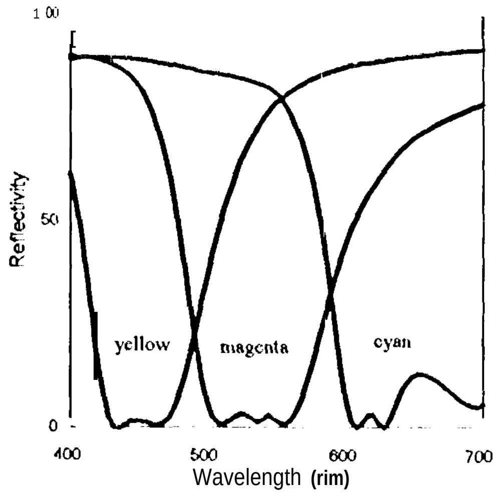

Fig. 2. Absorption spectrum of multiple layer metal film.

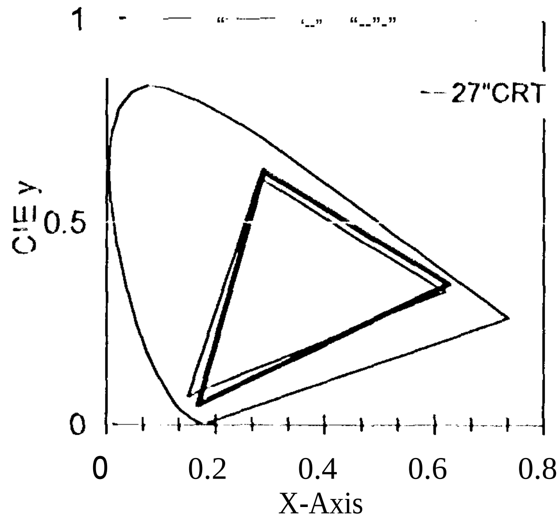

Fig. 3 Color gamut of SP color tunable filter.

If the SP resonance is wide enough to cover all of the visible spectrum, a white light modulator can be made. Fig. 4 show the theoretical calculation of using rhodium-aluminum two layer metal film system. Without voltage, the SP resonance is so wide that it covers all of the visible spectrum, and no light is reflected. When a voltage is applied, the reflected light begins to increase, and almost colorless. The highest reflectivity is over 80°/0, and wc have grey scales in between. The contrast ratio can be better than 200:1.

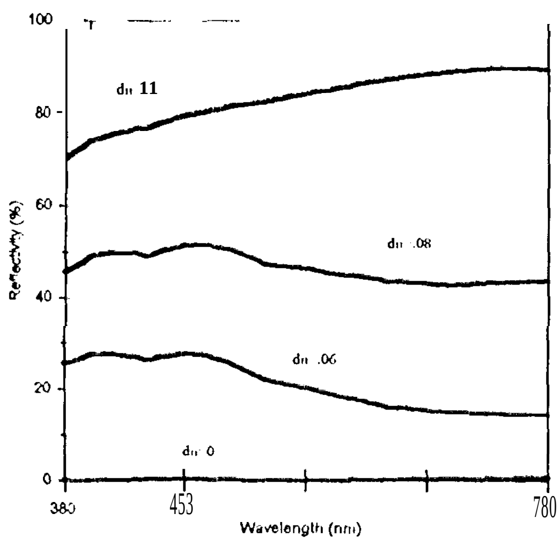

Fig 4 Theoretical calculation of reflectivity tuning ability using Al-Rh film When the index of liquid crystal changes from O to O. 11, the reflectivity changes from O to over 80%.

4. SP sequential color projection display

A sequential color SP projection display should be the first approach. Such a device can generate bright image with simple structure. It is formed by adding a many-pixel unit to the tunable color filter discussed above. This many pixel unit used Rh-Al film, and it has SP resonance wide enough to cover all of the visible spectrum, Fig. 5 shows the structure of such a device. The light from the lamp is collected by the reflector and then passes the front relay and the integrator to be.comes uniformly distributed collimated beam, After passing the polarizer, the p-component of the light beam is incident on the SP device, and being reflected four times inside the glass prism. The first three reflections function as a tunable color filter to provide the sequential primary colors (red, green and blue), and upon the last reflection, the many pixel unit creates the image. This image is then projected on a screen by the projection lens. To address the system, a semiconductor chip can be used as the substrate for this many pixel unit. Such a projector can generate very bright image since these units are working at the reflection mode, the substrate silicon is good heat conductor, ant{ another heat absorber can be attached to the silicon to extract the heat.

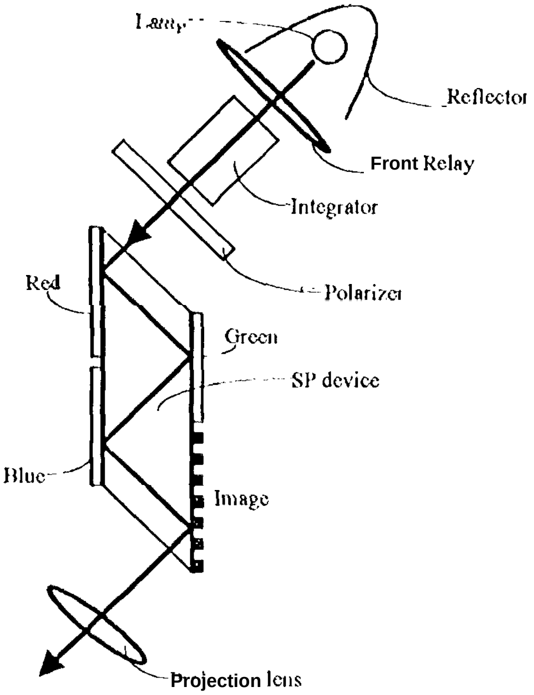

Fig. 5 Single panel surface plasmon projector. The first three reflections generate the sequential color, the last reflection generates the image.

The analysis of a 1.8" SP color sequential projector is listed in ~'able 1. By using the new Philips 100-w lamp with polarization conversion, its luminous efficiency can reach 3 Lumens/Watt, which is better than many of the three panel LCD light valve projectors. And the simple structure and compact size are the other important merits. Notice this device is a sequential color projector, which 2/3 of light is lost. The efficiency and brightness will be tripled if all of the colors are used, as we will discuss in the following section,

5. S1' "smart card" projector

Eventually, we want a projector can use all of the colors with simple structure, and the surface plasmon "smart card" is able to just do that. If we can reduce the size of the SP tunable color filter and fit it into a pixel, then each pixel can generate any color electronically, and such a single panel projector can have efficiency better than a 3-panel LCD projector. Consider a thin glass sheet has coatings cm both sides as shown in Fig. 6-a, one side of the glass sheet is coated with metal film and the other- side is coated with low index coating layer with thin film transistors(TFT) on top of the low index layer. Then many glass sheets (for example, 480 of them for a VGA display) are stacked with spacers in between and glued (6-b). And finally, a slice is cut off, polished and filled with liquid crystal (6-c) to become a SP smart card.

When a white light is incident on the S}' smart card, each ray is reflected six times inside a glass rod as shown in the top of Fig. 7; the three reflection on the top of each rod are just total internal reflections, while on the bottom of the rod, the three reflections function as a tunable color filter, by applied voltage, any color can be generated form the incident ray, and the overlaps of the three reflection curves can also provide the grey scale. Therefore the incident white light become a color image after passes through this SP smart card.

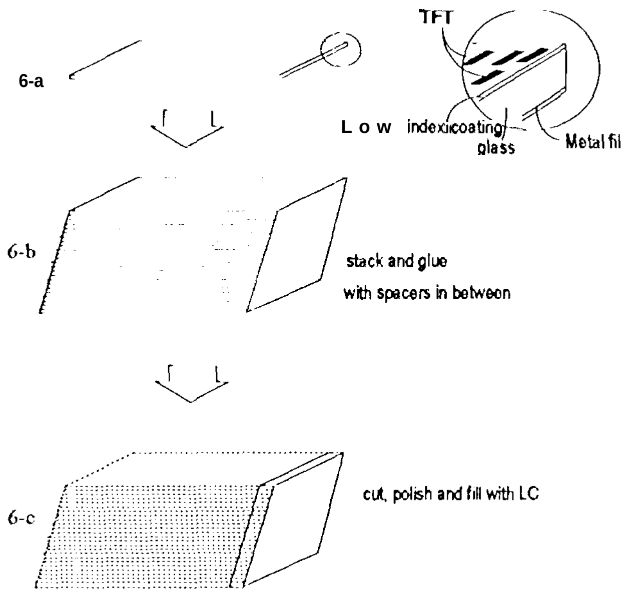

Fig. 6. SP smart card is made by staking long, thin glass rods filled with liquid crystal.

This S1' smart card has the same function as the three panel LCD light valve or three panel DMD, it is able to used all the colors all the time, but the structure is much simpler, since no color separation and color fusing are necessary, and only one projection lens is needed, the whole size of the projector can be reduced to a size smaller then a notebook,

For a SP smart card with VGA resolution, 48(MMOX3 transistors needs to be addressed. Fig 8 shows one possible design for the active matrix addressing. The connection of row lines are straight forward, the column

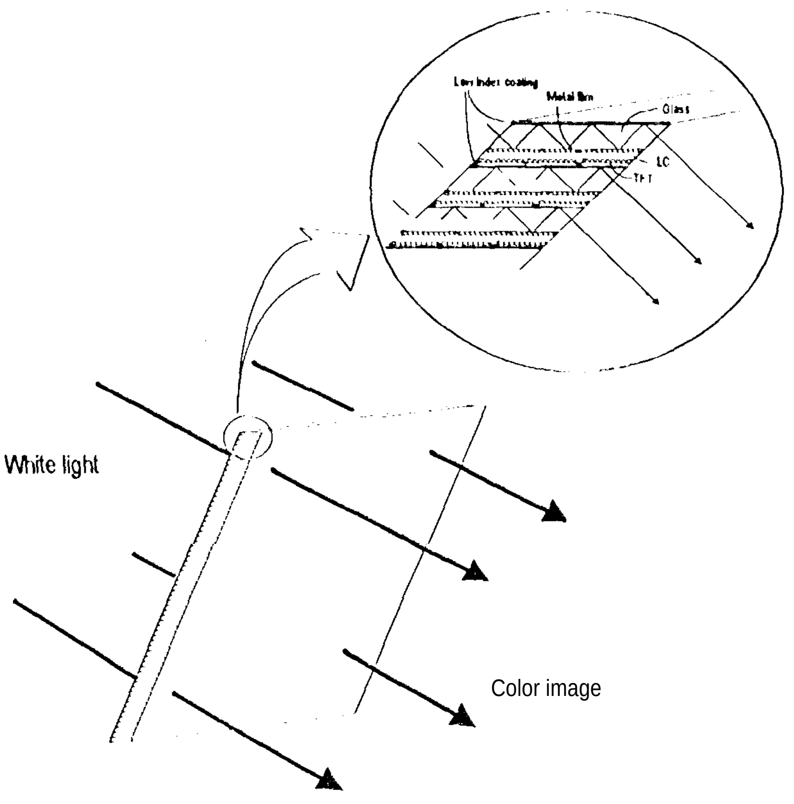

Fig. 7 A color image is generated by SP smart card after white light is reflected three times inside the card.

lines are thin metal strips run through the front face of the panel. Such thin metal wires would have a little effect on the efficiency, since most of the scat tered light generated by a very thin strip is in the forward direction.

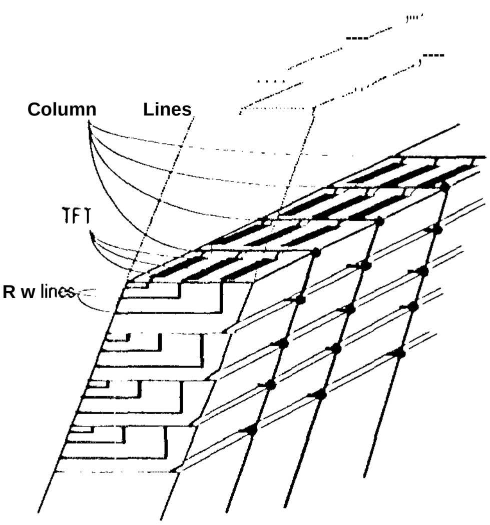

Fig. 8 Active matrix address for SP smart card.

Such a S1' smart card can reach very high efficiency with high brightness, analysis shows, for a 1.8" panel, the optical efficiency can be better than 20%, and using Philips lamp, the luminous efficiency can be over 10 lumens per watt ('I'able 1). In addition, the compact size and simple optical system structure make this device has the potential to be the leader in the projection display field.

This S}' smart card also can be used as a dir cct view display if a screen (like the one used in the rear projection TV) is attached to the exit face of this SP smart card. Since this card is made by stacking glass rods, the factors limiting the screen size of the direct view LCD displays (such the glass flatness, the liquid cryst al layer uniformity) are not applied here, the screen size can easily reach over 30".

For the conclusion, surface plasmon projection displays have shown great potential, such as high efficiency, high brightness, compact size and simple system st ructure. '1'bough there may be some uncertainties on the road as a new technology, the merits are clear. As the Japanese companies are so far ahead of us in the flat panel display field, a new technology maybe the only way for American companies to catch up.

References:

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Table 1 Lumen Output Estimate for 1.8" Panel Surface Plasmon Projectors

	Sequential Color	Smart-Card
Diagonal mm	45.7	45.7
Pixel H	640	640
Pixel V	480	480
Half Angle degree	6.65	6.65
F/#	4.31	4.31
Total Etendue	47	47
Etendue Correction	2	2
Usable Etendue mm^2-sr	?3.5	?35
Collection efficiency (1.0 mm arc)	0.79	0.79
Polarization convertion	0.8	0.8
Polarizer	0.88	0.88
SP tunable color filter	024	***
SP light modulator	0.85	0.72
Projection lens	0.85	0.85
Integrator	0.85	0.85
Light body overfill	0.903	0.903
Front relay	0.98	0.98
Color collection	0,75	0.75
Aperture ratio	0.95	0.9
Projector efficiency	0.065	0.219
Total lamp lumens	6000.00	6000.00
Projector lumens (1.0 mm arc)	310.11	1036.90
Luminous efficiency '(lum/W)	3.1	10.4