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The next generation of switchable glass : the Micro-Blinds

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Keywords

1=Switchable glass 2=smart windows 3=transmission 4=electrostatic actuator

Abstract

Switchable glass or smart windows have been developed and discussed for decades. They have bright futures in applications such as vehicle, architecture, privacy and energy efficient glazing among others. The existing technologies seriously suffer from customer acceptance. The next generation of switchable glass based on micro-blinds might help the incursion of smart windows to the market, or at least to some niche markets.

The micro-blinds are composed of invisible and electrostatically activated curling electrodes of 100 micrometers size. They can be deposited on flat glass by magnetron sputtering like regular low-E coatings, and then patterned by laser. They possess several advantages such as switching speed, UV durability, customized appearance and transmission, and do not employ costly ITO, relative to the current smart windows technologies: electrochromic, suspended particles and liquid crystals. Several groups have successfully developed curling electrodes for small area devices; the novelty of the proposed technology lies in the revolutionary and cost-effective processing scheme for large areas. This paper presents the status of our R&D project.

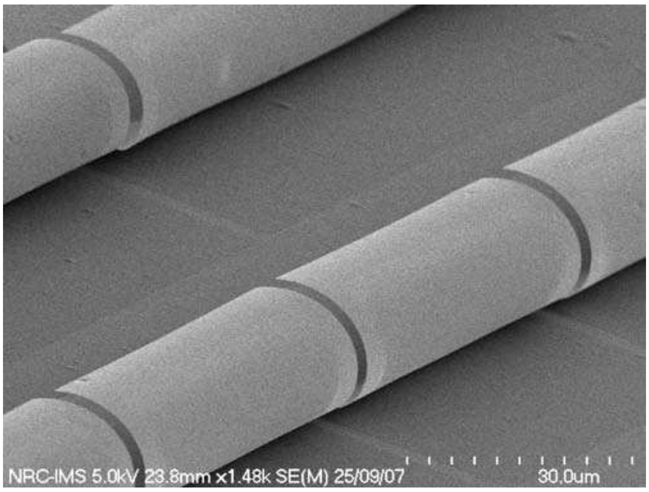


Figure 1.
SEM image of partially curled micro-blinds

Introduction

Smart windows are characterized by variable or controllable transmission of the light through them. Various types of smart windows have been developed for over two decades. Some technologies reached the market, for example, Ferrari's sunroof, Boeing's Dreamliner windows or Velux's skylight. However, for your house, would you pay 3 times the price of a regular skylight to be able to vary the transmission with pinholes and an on/off switching time of 10 min ? [1] In the literature, a lot of effort has been devoted on improving various existing technologies of smart windows; several hundred patents have been issued on electrochromism only. The performance of existing smart windows are very interesting, but not attractive enough to reach a large public, most probably due to some weaknesses such as cost, speed, appearance (tint) and range of transmission.

This paper presents the next generation of switchable glazing, based on micro-blinds [2]. They are not related to any previous work on internal macroscopic Venetian blinds [3-4]. The micro-blinds are really of micrometer size; this makes them practically invisible to the eye. They are curling electrodes activated by voltage. Smart windows based on suspended particles use voltage to align mobile needles, while the micro-blinds use voltage to unroll curled electrodes and thus block the light transmission. Figure 1 shows such curled electrodes: micro-blinds.

Such curling electrodes have already been developed and tested successfully by several groups [5-10] on small areas (1-10 cm^2) using standard semiconductor fabrication techniques. Moreover some patents [11-13] have been issued to other groups for similar rolling electrodes. These devices were developed for electronic (switches), optical (small visor or display) and biological applications. Such devices could be considered a type of Micro Electro Mechanical Systems (MEMS), some of which have reached commercial applications all around us (inkjet printers, cars (airbags, gyroscopes, tire pressure sensors), DLP projectors, etc). For example, some Digital Light Processing (DLP) projectors have millions of complex and tiny micro-mirrors activated by electrostatic forces. IMEC (Leuven, Belgium) recently presented a monolithically integrated 11 megapixel micro mirror array [14-15].

This paper presents a new application for the curled electrodes: smart windows. The main novelty is the proposed fabrication scheme making their manufacturing feasible and cost-efficient on large areas by using laser processing, instead of standard microelectronic techniques.

Fabrication

The fabrication process was designed to be performed on flat glass (large area), but it could also be applied to roll-to-roll manufacturing [2]. Figure 2 presents schematics of the cross-section of a micro-blind and illustrates some of the components and fabrication steps.

The first fabrication steps involve thin film deposition using common flat glass techniques like Chemical Vapor Deposition (CVD) or magnetron sputtering. The first layer could be any Transparent Conductive Oxide (TCO) such as SnO_2:F; i.e. any typical low-emissivity layer or TCO without the requirement of flow transmission of infrared wavelengths. Contrary to other smart windows technologies such as electrochromism, our micro-blinds are voltage driven, not current driven; thus the micro-blinds do not require low resistivity film such as the expensive Indium Tin Oxide (ITO) layer. For our proof-of-concept, we use regular low-emissivity glazing such as PPG SunGate 500™ or Solarban 60 ™. A thin dielectric is then deposited followed by a sacrificial layer. Finally the stressed layer is deposited. There are numerous possibilities for the layers, in our case we use amorphous silicon for the sacrificial layer and chromium for the stressed layer. Inorganic materials have been preferred to obtain good UV durability. There are different techniques to control the intrinsic stress in the curling layer. Our proof-of-concept device has a stress layer consisting of tensile and compressive chromium deposited by magnetron sputtering. The stress level is simply controlled by varying the Ar pressure during sputtering of the Cr. Figure 3 shows a test device (coil, not a micro-blind) consisting of 8 turns of the stressed layer. We have obtained stressed rolls of radius of curvature as small as 3 μm.

As mentioned before, one of the novelty of the micro-blinds is the use of laser processing to define their geometry allowing manufacturing on large area without contact. Laser thermal anneal activates the intermixing of the sacrificial layer and the stress layer, thus forming an anchor and etch stop (for the release process). Similar laser annealing of amorphous silicon has been developed for displays [16]. A laser ablation step defines the opening to release the curled micro-blinds. The proof-of-concept device has been fabricated by conventional lithography and etching methods, but laser tests were performed on the layers as shown in Figure 4 and 5. Figure 4 shows an oblique SEM view of a laser ablation of the sacrificial and stress layer.

The thin film deposited samples were mounted on a computer controlled CAD/CAM driven motion stage with vacuum hold-down fixture. Patterning of the coated thin film was carried out by the X-Y motion stage, which had a linear positioning accuracy of 1 μm. The processing feed rate was maintained at 5-10 mm/min. The experiments were performed in air using a Spectra-Physics Model:YHP40-532 nanosecond pulsed laser system, which delivered 30 ns pulses with an average power of 1 W at a wavelength of 532 nm and with pulse repetition rate of 1 kHz. After collimation with an 8X beam expander, the laser beam was focused using an f/50 mm lens. During experiments the ablation width was varied from 4μm to 9 μm for repetition rate of 500 and 1000 Hz. The laser fluence incident on the samples was controlled using a set of neutral density filters. The laser focal spot was also slightly defocused to avoid damage to the Si layer and to adjust the ablation track width the diode current was monitored. Although in these experiments, the

Figure 2.

Schematic views of a micro-blind's cross-section

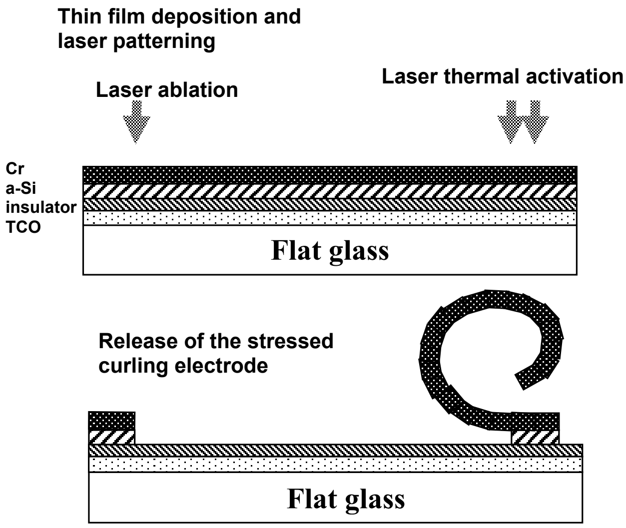
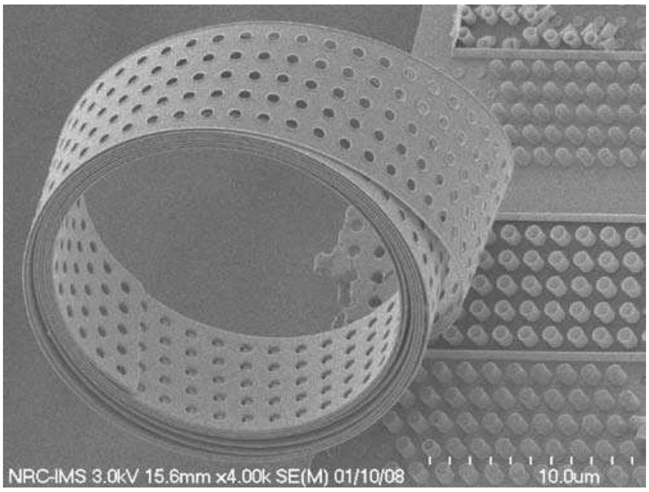


Figure 3.

SEM image of stressed chromium layers after release (400 μm long by 0.1 μm thick)



patterned lines are relatively rough, much smoother line shape could be obtained by using smaller spot size and by optimizing other conditions such as the spot overlap of the laser beam. Line edge roughness smaller than 1 μm have been obtained for the ablation of ITO [17]. Figure 5 shows a cross-sectional SEM view of the ablated layers. It shows various layers and points out only the stressed and sacrificial layers were ablated, not the layers underneath.

The next processing step (which could be performed at the Insulated Glass Unit (IGU) manufacturing site) is the release of the micro-blinds by etching the sacrificial layer. Wet or dry etching could be used. Dry etching using fluorocarbon plasma chemistry was preferred as it is clean and fast. Then the samples are ready for electrical actuation.

Results

Once the micro-blinds are released on the proof-of-concept devices (10 cm^2 square glass pieces) electrical testing was performed. Actuation voltages as low as 20-30 V have been observed. Closing (roll-down) delay of the order of the ms is typical (in agreement with other types of curling electrodes [5-9].

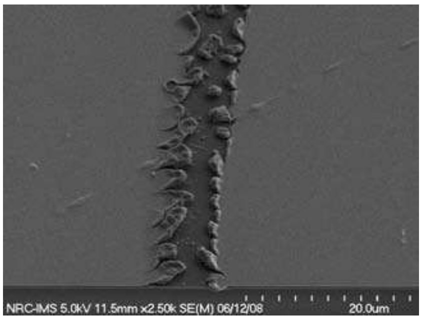


Figure 4.

Chromium and amorphous silicon layer ablated by laser

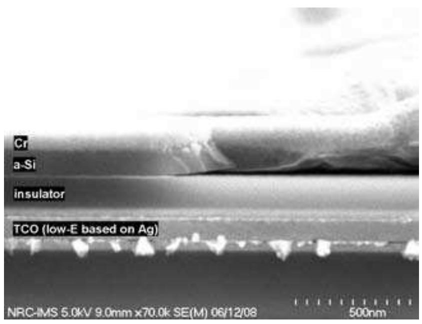


Figure 5.

SEM cross-sectional view pointing out that the ablation only affected the Cr and a:Si layers

Opening (roll-up) delay seems a slightly longer, but still below one second.

Visual appearance can be neutral, there is no strong unappealing tint such as observed on other types of smart windows. The weak tint is related to the TCO layer and can be very minimal. Moreover, the appearance in the open and closed state can be customized to the choice of the user. Haze or scattering is minimal, probably similar to the Suspended Particles Devices (SPD) technology. Since micro-blinds are made of inorganic and high temperature melting materials, they are very resistant to temperature variations.

More work in underway to get a better understanding of the behavior and solving several open issues (materials science, electrostatic, etc).

Table 1

Comparison of performances Micro-blinds vs existing technologies for smart windows

Parameters	Electrochromism (18)	Suspended particles (19)	Micro-blinds
Transm. visible max	62%	50%	~65%
Transmission solar range	30%	30%	~60%
Appearance	Yellow-blue	Neutral,Blue tint	Neutral, custom
Speed	Slow (1-10 min)	Fast (few seconds)	Ultrafast (ms)
Operation voltage	1-5 V	50-120 V	30-50 V
UV resistance	Good	Good	Excellent
Temperature operating range	Approx. -30 ° to 70° C	-40° to 100°C	Very wide ~-50° to 300° C

Discussion

The micro-blinds are a new idea for smart windows. They are following extensive work from several groups on curling switches or actuators [5-9] proving their reliability. The use of laser processing could make them cost-efficient for smart windows. There is still considerable amount of work to be done to prove their manufacturing feasibility on large areas. Nevertheless, laser patterning is a sector developing rapidly and of great interest for the flat panel display industry. Moreover, current FPD techniques like projection lithography could also be used to fabricate micro-blinds but with a cost limiting the sector of application.

The micro-blinds have a great potential to attract end-users, their expected performances compare very well with the other existing technologies for smart windows, as illustrated in table 1.

The predicted characteristics of the micro-blinds compare very well with the measured ones from the other technologies of smart windows. Note that we did not include the liquid crystals since they are mainly oriented toward partitions or interior privacy applications, while the micro-blinds require double glass panels such as the IGUs.

In case of power failure, the micro-blinds would go in open state, contrary to the SPD (safety hazard). SPDs and rolling electrodes (micro-blinds) are expected to have remarkable low power consumption of approximately 1 W/m2 [20]. Both SPD and EC smart windows are characterized by very low UV transmission (<1%), the micro-blinds in the opaque state could also have very low UV transmission. However, contrary to the existing technologies, the micro-blinds could be designed if requested to have a notable UV transmission to the benefit of the occupant's health. The lack of UV exposure in our environment (work, house, school, etc) has been identified as a possible cause of Sick Building Syndrome (SBS)[22]. Reduced fading of colors induced by UV and visible on fabrics like curtain does not seem a very good selling argument, compared to the occupant's health.

Smart windows have the potential to reduce the glare, improve privacy (increase the comfort of the occupant) as well as save energy [22]. Reducing cooling load (opaque) and automatized –optimized daylighting are two major ways to save energy. Moreover, two unique characteristics of the micro-blinds make them even more attractive for energy savings: they are not opaque but are reflective (better thermal performances), and have a higher solar transmittance range (suitable for passive solar heating).

Conclusions

Micro-blinds are a new type of smart windows based on stressed curling electrodes actuated by electrostatic forces. They possess several favorable characteristics (speed, cost, durability, appearance, etc) giving them a bright future. More work is needed to prove their reliability and laser manufacturability.

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