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LASER SCRIBING OPTIMIZATION OF RF MAGNETRON SPUTTERED MOLYBDENUM THIN FILMS

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The optimization process of laser scribing of back contacts is carried out by varying different parameters of laser and thickness of Molybdenum (Mo) thin-films. Mo thin films were deposited by RF magnetron sputtering on the organically cleaned soda lime glass substrate. The thickness of Mo was in the range of 60 *nm to* 800 *nm. For the scribing process the laser power and the laser pulse frequency were varied. Different thickness of Mo shows the different scribe behavior. The optimized process provides a successful isolative laser scribing, having a minimum scribe line width, of Mo layer on glass substrate without any presence of walls, ridges, or collars in scribed areas.*

Keywords: *LASER SCRIBING, MOLYBDENUM THIN FILM, LASER POWER, PULSE FREQUENCY, SCRIBE LINE WIDTH.*

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1. INTRODUCTION

Thin film solar cell technology provides a best solution towards more economic solar cell energy. The first step in manufacture of thin film solar cell is the deposition of molybdenum (Mo) back contact layer on soda lime glass substrate and the next step is the isolative laser scribing of this layer for making a metal back contacts between the layers. However, the problems are arising with a heat-affected zone around the scribed area due to the laser pulse beam [1]. The scribing should be done in such a way so that the scribed line should not contain bridges or process residue in the grooves that could cause an electrical connection and short-circuit the cell [2]. To increase the solar cell efficiency, the scribing of Mo layers desires minimum scribed area to have maximum active solar cell area [3] and so, minimize the dead area in the cell. Optimum operation for thin-film PV materials has been investigated by several PV manufacturers [4, 5, 6].

In this study, we present the results regarding the optimization of isolative laser scribing of sputtered-Mo thin-film deposited on soda lime glass substrate. The optimization process is performed by varying different laser parameters and thickness of the Mo thin-film in order to achieve lowest resistivity films. The result of successful scribing yields reliable, reproducible clean scribes without any presence of the buckling, ridges, or collars in the scribed areas.

2. EXPERIMENTAL

The processes of laser scribing of Mo thin-films were done using commercially available the laser system that has the multi diode pumped fiber laser (20 W average maximum power) [Model No. Akhsar Fiber-Pro, Sahajanand Laser Technology Ltd., INDIA] Mo thin films used for the scribing have a different thickness from 60 nm to 800 nm. Mo thin films were deposited by RF magnetron sputtering at 1mTorr working pressure and 100 W RF power. The electrical property viz. sheet resistance of the Mo thin films was measured using four point probe method. The laser system, which was used for the scribing of Mo thin film, has a specification shown in Table 1.

Table 1 *– Laser system parameters used for the scribing the Mo thin films*

Laser	Multi Diode Pump Fiber Laser
Nominal average power	20 W (optional 10 W)
Maximum peak power	> 7.5 kW
Power tunability	10 - 100 %
Pulse repetation rate	20 - 80 kHz
Wavelength	1060 ± 10 nm
Pulse duration@20 kHz	<120 ns
Class	IV
Power stability	> 95 %
Pulse energy@20 kHz	1 mJ
Beam quality	1.5 (M^2)
Output beam diameter($1/e^2$)	9 mm
Scribe speed	upto 1000 mm/s
Inbuilt guide (marking) laser	He-Ne laser (660 nm & 0.5 mW)

In our study we have kept the scribing speed constant at 500 mm/sec in order to achieve lowest scribed width. Scribing process of Mo thin film was optimized by varying both the laser power and the pulse frequency simultaneously. First keeping the maximum average power 20 W and varying the pulse frequency from 1 to 80 Hz to get the optimum pulse frequency and by using that, vary the average power up to minimum of 1 W. Different thickness of the Mo shows different kind of scribe pattern. The smoothness of the scribed was observed using a polarization microscope (LABOURLUX 11, Leitz).

3. RESULTS AND DISCUSSIONS

Mo thin films having different thickness (60 nm to 800 nm) shows a different electrical conductivity [7]. The measured sheet resistance of the Mo thin films as a function of thickness of the films is shown in Fig. 1. Different thickness of the Mo thin films shows different kind of the scribing behavior. Ablation with a train of laser pulses per spot and scribing lines were performed on molybdenum back-contact from film side. The laser spot overlap along a scanning line was controlled by the translation speed at a constant pulse repetition rate.

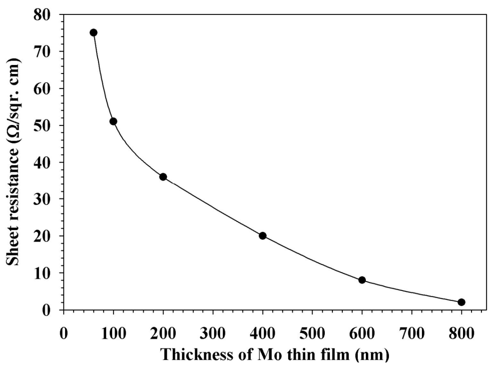


Fig. 1 *– Variation in the sheet resistance of Mo thin films as a function of thickness indicates that higher thickness shows higher conductivity*

Various combinations of laser power and pulse frequency were used for selective ablation of the films. Optimal regimes for laser processing of each layer were estimated depending on the Mo film thickness. The beam overlap or the number of pulses played an important role in the processing selectivity because the ablation threshold was sensitive to accumulation of the irradiation dose.

3.1 Effect of laser power and pulse frequency

However, at certain scribe parameters, namely the laser power together with laser scribe speed and pulse frequency, the scribes were superior to the high-energy scribes in two immediate respects: 1) The scribe profile had sharply defined edges without significant formation of walls, and 2) the glass remained undamaged, glass damage invariably appearing at higher energy densities.

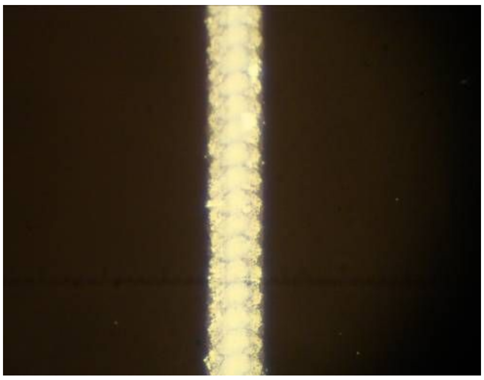


Fig. 2 *– Sharp scribed line (140 μm) of Mo thin-film has 2 watt laser power and 1 Hz pulse frequency*

The scribing image (Fig. 2) of Mo thin films that has continuous and regular overlapping of the laser spots forms the sharp edge scribe. In addition there were no collars and ridges left at the scribe edge. The scribed line width, which is important parameter in the patterning of the semiconductor single or multi layers, is mainly depending on laser power and pulse frequency. Laser power varies in this study is from 20 W to 2 W and the pulse frequency varies from 1 Hz to 80 Hz. Fig. 3 shows the obtained comparative results of the scribed line of Mo thin film (60 nm) by varying the laser power and pulse frequency. By increasing the laser power and laser pulse frequency, the scribed line width increases. For higher laser power i.e. 20 W, the width of the scribed line was 240 μm at 1 Hz pulse frequency and 390 μm at 80 Hz pulse frequency. While at lower laser power i.e. 2 W, the increase in the width of the scribed line was negligible.

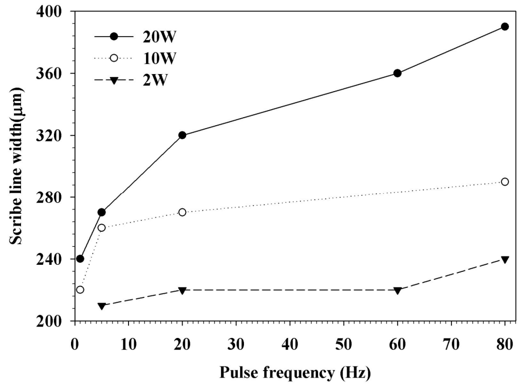


***Fig. 3** – The variation of the scribed line width of Mo thin film (60 nm) as a function of laser pulse frequency shows that as the laser power and the pulse frequency were set at minimum level, the scribe line width is lower*

The scribed line width should be kept minimum for its future use in the patterning the different semiconductor devices. From Fig. 3, we said that at 2 W laser power and 1 Hz pulse frequency we get the minimum scribe width i.e. 210 μm. The 210 μm is still a higher value. Therefore, by using the optimal laser parameters for 60 nm Mo film thickness i.e. 2 W laser power and 1 Hz pulse frequency we scribed the higher thickness of Mo thin film.

Fig. 4 shows the variation in the scribe line width as a function of pulse frequency. In this scribing, we found that as the pulse frequency reduces the scribe line width reduces. The minimum scribing width was 30 μm for 2 W laser power and 1 Hz pulse frequency. We had also scribe the different thickness of Mo thin films at 2 W laser power and 1 Hz pulse frequency and got the similar kind of variation. From that variation, we can say that as the thickness of the Mo thin films increases the scribed line width decreases, too, this is shown in Fig. 5.

At low power (2 W) and low frequency (1 Hz) we have achieve the minimum scribe line width i.e. 40 μm (Fig. 5a). In order to achieve lowest scribe line width without any presence of walls and collars in the scribed area, we scribe the higher thickness Mo films at 0.2 w laser power and 1 Hz pulse frequency, as shown in Fig. 5b. At 0.2 w laser power and 1 Hz pulse frequency the minimum scribe line width is 38 mm. We also try the lower thickness of the Mo thin film for the 0.2 w laser power, but due to the lower thickness, the films experienced a stress, so, the scribe line was distorted or not uniform. Such scribe lines observed using the polarization microscope is shown in Fig. 6.

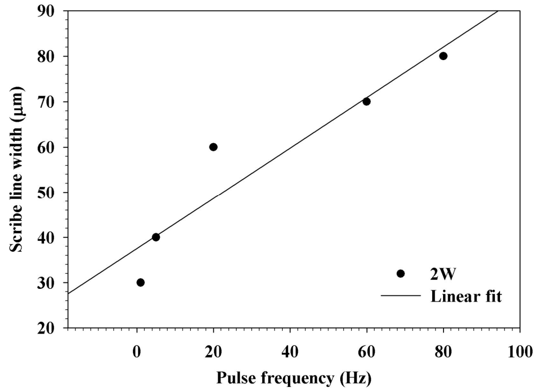
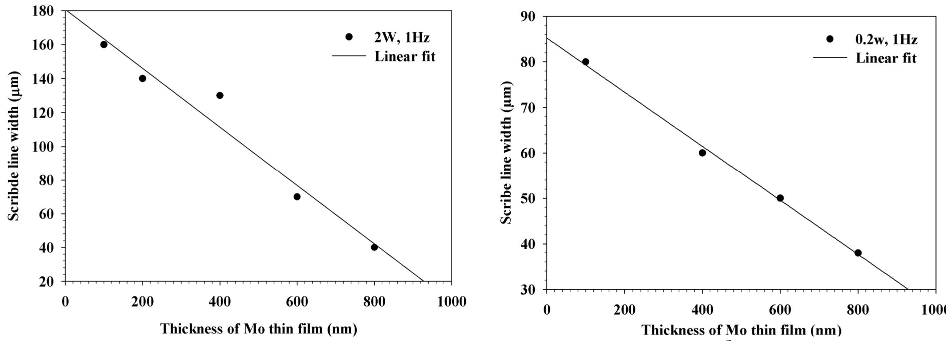


Fig. 4 *– The variation of the scribed line width of Mo thin film (*800 *nm) as a function of laser pulse frequency shows that as the pulse frequency was reduces; the scribe line width is decreases*



a b

Fig. 5 *– Scribed line thickness is decreases as the thickness of the Mo thin film increases at 2 W laser power and 1 Hz pulse frequency (a) while at the same frequency and* 0.2 *w laser power the minimum scribe line width observed (b)*

3.2 Scribe quality

However, the great results were extremely rare and seemed to occur within a process window of miniscule proportions. During the extensive experimentation only a handful of 40 μm scribes were achieved with good results. Nonetheless, the excellent quality of these scribes invite to speculation as to whether some alterations could be made to the system in order to achieve such scribes. Scribe results often terrible, with big shards and cracks. The high energy scribe results that are referred to as good on the other hand are not square. Viewed from the top they have a typical pulse-to-pulse appearance of slightly overlapping circular holes. If the work piece speed is too high the pulses will loose their overlap and bridges will occur. If the work piece slows down the “lips” that protrude into the scribe tend to flake up more readily.

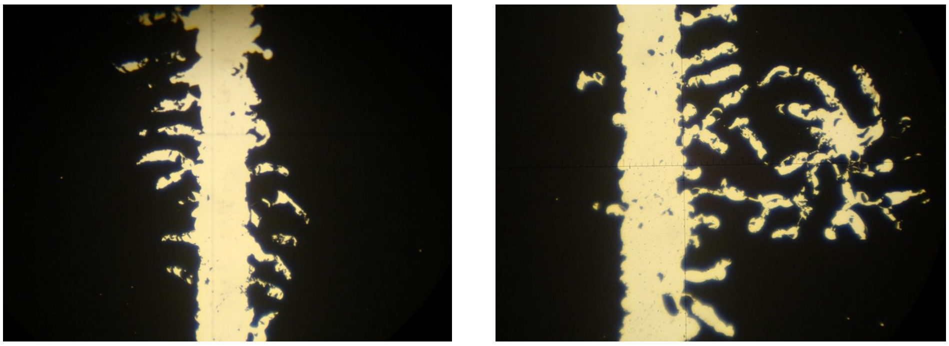


***Fig. 6** – Stress introduce in the lower thickness of Mo thin films while scribing so, the scribe line becomes non-uniform*

In order to achieve the better quality of the scribe line we vary the laser power and pulse frequency for the different thickness of the Mo thin films. Ablation with a train of laser pulses per spot defines the scribe quality. Theoretically, the pulse train of the laser scribe the material is shown in Fig. 7. Some calculations were made in order to establish the geometrical situation [8, 9] during the laser pulse.

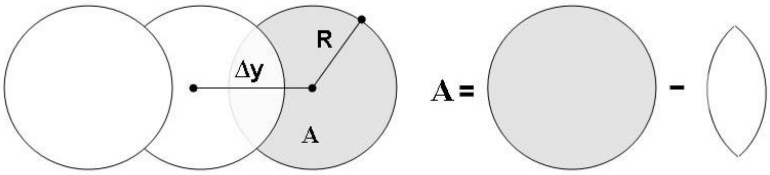


***Fig. 7** – Geometrical representation of exposed area*

Given that the laser spot has a radius, R, and is repeated with a frequency onto a sample that is moving with the speed, v, one can express the surface area A of each consecutive pulse as the spot size minus the overlap of pulses (see Fig. 7). This area can be considered as the area of film removed per pulse.

$$A = \pi R^2 - 2\left(R^2 \arccos\left(\frac{\Delta y}{2R}\right) - \frac{\Delta y}{2}\sqrt{R^2 - \frac{\Delta y^2}{4}}\right) \tag{1}$$

where Δy is the distance between consecutive pulse centers.

$$\Delta y = v \times \frac{1}{f} \tag{2}$$

The obtained exposed area (scribe line width) of the scribe line of different thickness of the Mo thin films is shown in Fig. 8.

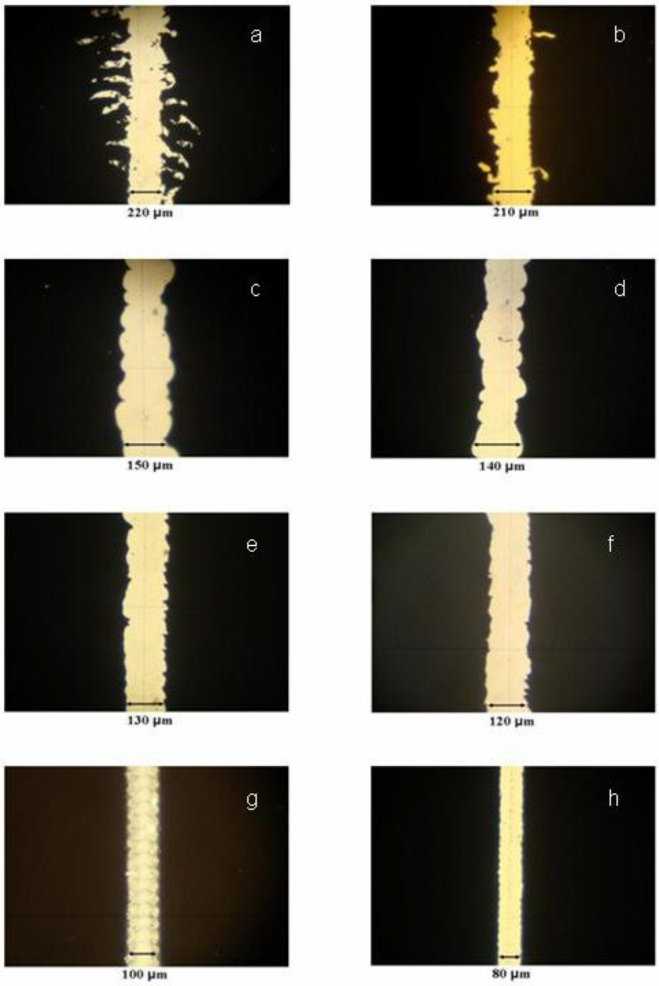


Fig. 8 – *Scribe line width of Mo thin films of different thickness i.e. from (a) to (h) is* 60 *nm to* 800 *nm, results of an average laser power is 2 W and 5 Hz laser pulse frequency*

As increasing the thickness of the Mo thin films, we saw from the Fig. 8, that the scribe line width decreases. At the higher thickness of the Mo thin films, we got the better scribe area as well as the minimum side edges. For 800 nm thin Mo films, the minimum scribe line width i.e. 80 μm was obtain (Fig. 8h). The maximum scribe line width, i.e. 220 μm, with poor scribe area is observed at 60 nm thin Mo films (Fig. 8a).

4. CONCLUSIONS

The presented work shows a process of laser scribing for Mo thin-film of different thickness (60 nm to 800 nm) has been considered. Laser parameters have been determined that provide reproducible, good scribes, that do not present any unwanted bridges. Scribing is performed at energy densities of around 1 mJ at 20 kHz, with a pulse-to-pulse overlap by the relation between laser power and laser pulse frequency. Considering the laser scribing step, molybdenum having a higher thickness yield better results compare to the lower thickness. Lower thickness of Mo shows the non uniform distribution or dull scribe edges of the scribe line. The scribe line width is observed minimum (80 μm) at higher thickness (800 nm) and maximum (390 μm) at lower thickness (60 nm).

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