Chapter 3

Molybdenum Back-contact Layer: Growth and optimization
MOLYBDENUM BACK-CONTACT LAYER: GROWTH AND OPTIMIZATION

Molybdenum (Mo) thin films are most widely used as an ohmic back-contact for copper indium diselenide (CIS) and its alloy copper indium gallium diselenide (CIGS) based thin film solar cell. Radio frequency (RF) magnetron sputtering system is used to deposit Mo thin films on soda lime glass substrate. The deposition was carried out using argon (Ar) gas at different Ar controlled (working) pressures (1 to 10 mTorr) and at different RF powers (60 to 100 W). The influence of both the working pressure and the RF power on the Mo thin films was studied by investigating its structural, morphological, electrical, and optical measurements. The results reveal that a stress-free, low-sheet-resistance (~1 Ω/ ), and reflecting (~55 %) Mo thin film grown at 1 mTorr working pressure and 100 W RF power.

3.1 NEED OF MOLYBDENUM BACK-CONTACT LAYER

Molybdenum (Mo) thin films are used as a back-ohmic contact widely in copper indium diselenide (CIS) and its alloy, copper indium gallium diselenide (CIGS) thin film solar cells. The metallic back-contact, Mo, serves as substrate on which the absorber layer i.e., CIS/CIGS is deposited. Mo is more favorable as a back-contact layer in CIS and CIGS thin film solar cells because its diffusion into the absorber starts above 600 °C [43] and, in addition, it offer a resistance to alloying with copper and indium [44]. Studies on the deposition of the Mo thin films by radio frequency (RF) magnetron sputtering have been reported in the literature [45,46] and, recently, about 20 % energy conversion efficiency [47] has been reported for CIGS thin film solar cell. The adhesion property of the Mo thin film, which has direct impact on the film resistance, depends on the deposition parameters like RF power, working pressure, etc. Studies on the correlation between the working gas pressure and growth of the film have been reported in the literature [48, 49].

In the present work, the emphasis was to deposit Mo thin films using the RF magnetron sputtering to achieve a low resistive and a well adherent Mo thin film. In order to achieve the above requirements the RF power was varied from 60 to 100 W and the working pressure was varied from 1 to 10 mTorr. The structural, morphological, electrical, and optical properties of the Mo thin films were studied as a function of RF power and working pressure. Furthermore, the laser scribing of the molybdenum thin film having different thicknesses

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were done and optimized the void free clean scribing condition, that will be use in future for the solar cell module preparation.

3.2 THIN FILM PREPARATION

Mo thin films were prepared on organically cleaned soda lime glass substrate (50 mm × 50 mm) by using the circular RF magnetron sputtering system, (Huttinger Elektronik 600 W, U.S.A.), at different working pressures and different RF powers. The distance between Mo target (2-inch diameter, 5 mm thick) and the substrate was 90 mm and the substrate’s rotation was kept at ~ 40 rpm to obtain uniform film. The thickness was kept constant at 1000 nm for all deposition and it is measured in-situ by using a quartz crystal thickness monitor. The argon (Ar) gas was used as a sputtering gas, whose flow was controlled by the mass flow controller (MFC, AALBORG, Germany). The deposition of Mo thin films was carried out in vacuum coating unit (model - 15F6 HINDHIVAC, Bangalore, India).

The following process was used for the deposition of all Mo thin films. Initially, the chamber was evacuated to a base pressure close to 1 × 10⁻⁵ mbar. Then the Ar gas was introduced into the chamber using a needle valve. Using the Ar flow, we set the chamber pressure at a desired working pressure and, subsequently, by throttling the high vacuum valve the pressure was maintained at the desired value during the deposition process. Before initiating the actual deposition of Mo layer on soda lime glass substrate, the target was pre-sputtered for 5 minutes to remove surface contamination, if any. We have first grown Mo thin films by varying the working pressure from 1 to 10 mTorr and keeping the RF power constant at 100 W. Subsequently, the films were characterized to find out the optimum pressure; thereafter, the films were prepared at this optimum pressure by varying the RF power from 60 to 100 W. All prepared Mo thin films were characterized by GIXRD, AFM, four-point probe method, and optical reflectivity measurements.

3.3 EFFECT OF WORKING PRESSURES

3.3.1 Structural Characterization

The influence of the working pressure (1 to 10 mTorr) on the Mo thin films can be observed from the XRD spectra shown in Fig. 3.1, in terms of full width half maxima (FWHM) and the shifting of the 2θ value from its bulk value i.e., 40.05°. From the values of FWHM, the crystallite size (D), was calculated using the Scherrer's formula (Equation 2.2). The observed d-value of (110) plane for 1 mTorr is matched with the JCPDS data card 01-1208. By using
the d-value and the corresponding (hkl) value of the peak, the lattice constant, \( a \), was derived from the relation [50],

\[
d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}
\]  

(3.1)

The variations in the value of \( a \), and \( L \) is shown in Table 3.1. From the XRD spectra, shown in Fig. 3.1, the change in the FWHM of the (110) peak and the shifting of the 2\( \theta \) value from its bulk value i.e., 40.05°, for the same peak are clearly noticeable.

The broadening of the FWHM and the shifting of 2\( \theta \) value are both related to the structure defects in the films and so, indication of the stress present in the film. The stress is directly related to the lattice strain. The percentage of strain is determined from the lattice constant, \( a \), [51],

\[
\text{strain(\%)} = \frac{\Delta a}{a_0} \times 100
\]  

(3.2)

where \( a_0 \) = bulk lattice constant of Mo = 3.1469 Å, and \( \Delta a \) = difference between the lattice constant of observed Mo thin film and the bulk Mo. Knowing the strain, we can estimate the isotropic stress [52],

\[
\sigma = \frac{E}{2 \nu_f} \times \frac{a_0 - a}{a_0}
\]  

(3.3)

where, \( E \) is the Young modulus and \( \nu_f \) is the Poisson ratio.

For the calculation of the stress, we have used the bulk values of \( E \) and \( \nu_f \) viz. 3.36 \times 10^{11} \text{ Nm}^{-2} \) and 0.298, respectively [53]. The values of crystallite size, \( D \), lattice constant, \( a \), percentage strain, estimated stress, 2\( \theta \) angle and its corresponding d-values for Mo thin films grown at different working pressures are tabulated in Table 3.1. At lower working pressure (1 mTorr) the highest crystallite size, 14.3 nm, was observed, which shows the improvement in the crystallization of the Mo thin films.
Fig. 3.1 The XRD spectra of the Mo thin films grown at different working pressures (from 1 to 10 mTorr) and a constant RF power (100 W) show that by increasing the working pressure the crystallinity of the Mo thin film degrades due to the decrease in the deposition rate.

During the deposition of the thin films, the strain or stress arises from the incomplete process of structural ordering occurring during the film growth and may be due to the substrate contamination. The grain growth process in the film mainly depends on the deposition or condensation rate and the deposition temperature.
Table 3.1 The \(2\theta\) value of the (110) plane, its corresponding d-value, crystalline size, L, and lattice constant, a, of Mo thin films grown at different working pressures by keeping the RF power constant at 100 W.

<table>
<thead>
<tr>
<th>Working Pressure (mTorr)</th>
<th>d-value (Å)</th>
<th>(2\theta) (degree)</th>
<th>Crystalline size, D, (nm)</th>
<th>Lattice constant, a, (nm)</th>
<th>Strain (%)</th>
<th>Stress ((\times10^9) Nm(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.22174</td>
<td>40.572</td>
<td>14.32</td>
<td>0.314</td>
<td>0.1562</td>
<td>0.88</td>
</tr>
<tr>
<td>5</td>
<td>2.27067</td>
<td>39.661</td>
<td>5.67</td>
<td>0.321</td>
<td>2.0427</td>
<td>-11.51</td>
</tr>
<tr>
<td>10</td>
<td>2.33142</td>
<td>38.586</td>
<td>3.77</td>
<td>0.329</td>
<td>4.7728</td>
<td>-26.90</td>
</tr>
</tbody>
</table>

By varying the working pressure, the deposition rate varies. At lower pressure, at 1 mTorr, the collisions of the sputtered particle with the gas will be reduced and therefore the deposition rate higher \(~0.32\) nm/s in our case. Owing to this, the sputtered particles with its improved energy reduce its arrival angle to the substrate. Thus, the possibility of the formation of inter-granule void reduces, which, in turn, results in the dense structure of the grains and hence the improvement in the crystallinity of the film [52]. The higher crystallite size, 14.32 nm, due to the dense microstructure of the film was observed at 1 mTorr working pressure shown in Table 3.1.

On the other hand, at a higher pressure, greater than 5 mTorr in our case, due to the multiple collisions of the sputtered particle with the gas, the deposition rate is reduced, \(~0.23\) nm/s at 5 mTorr and \(~0.15\) nm/s at 10 mTorr. This leads to a reduction in the energy of the sputtered particle as well as an increase in the average angle of arrival at the substrate. This results in the formation of porous grain growth and inter-granule voids. This deformation of the crystallinity of the film leads to an increase in the lattice constant and thus introduces strain in the film. In addition, the crystalline size reduces to 5.67 to 3.77 nm, as the working pressure increases from 5 to 10 mTorr respectively.

The stress values, as obtained by solving Equation 3.3, for different lattice constants of Mo thin films, which are grown at different pressures, are tabulated in Table 3.1. For pressures greater than 1 mTorr the value of lattice constant is lower than the bulk value, i.e. 0.314 nm, due to which the grains of the film experience a tensile force between them. The negative and positive signs in Table 3.1 indicate a compressive stress and a tensile stress, respectively. The stress in the film does not allow the grains to accumulate uniformly to the surface of the substrate. In our case, we experienced that at greater than 5 mTorr pressure, due to the considerably low deposition rate, the grains were not conglomerate together, and formed a surface having pinholes or scratch-like morphology.
3.3.2 Morphological Characterization

The study of the surface morphology of the RF magnetron sputtered Mo thin films was carried out using AFM. Figure 3.2 shows the AFM images of Mo thin films grown at different working pressures (1 mTorr to 10 mTorr) by keeping the RF power constant at 100 W. From the AFM images, we observe that the average grain size, and hence the surface roughness, decreases as the working pressure increases. As a result, the surface homogeneity is degraded and becomes porous. At 10 mTorr pressure, the ‘scratch-like’ appearance of the film surface having a surface roughness 1.87 nm was observed. This observation, as already analyzed by GIXRD measurements, is due to the lower deposition rate. By lowering the working pressure, viz. ~1 mTorr, due to the higher deposition rate, a uniform surface morphology is observed which has a higher surface roughness viz. 7.78 nm.

Fig. 3.2 The AFM images of Mo thin film at different working pressures from 1 to 10 mTorr shows that by reducing the working pressure from 10 to 1 mTorr, the uniformity in the grain coalescence improves significantly.
3.3.3 Electrical and Optical Characterization

The sheet-resistance is a crucial parameter in the application of the solar cell. Minimum sheet-resistance of Mo thin film gives minimum series resistance of the solar cell and that, in turn, improves the final efficiency of the solar cell. Figure 3.3 shows the sheet resistance, using the four-probe technique, of the Mo thin films deposited at different working pressures.

![Sheet resistance vs Working pressure](image)

**Fig. 3.3** The sheet-resistance of Mo thin films at different working pressures by keeping the RF power constant at 100 W, which shows that at lower working pressure viz. 1 mTorr, the sheet-resistance is lowest.

Increasing the sheet-resistance as increasing the working pressure is shown in Fig. 3.3. At higher sputtering pressure is a direct result of the sputtering induced porous structure that has a greater number of grain boundaries [54] (as observed from the AFM results) compared to the lower working pressure Mo thin film. As we move towards the lower pressure, the porosity reduces and hence the sheet-resistance decreases. The sheet-resistance at 1 mTorr working pressure and 100 RF power was \( \sim 1 \ \Omega/\square \).

In the optical study, we have measured the reflectivity of the Mo thin film, shown in Fig. 3.4, for film grown at different working pressures by keeping the RF power constant at 100 W. The optical reflectivity plays an important role in the solar cell application. Highly reflective back-contact improves the absorption in the absorber layer. At 1 mTorr working pressure we observed highly reflective silvery white Mo thin films. By increasing the
working pressure isolated columnar crystallites, can be observed from the AFM images, reduces the optical reflectance. J.A. Thornton et al., [55] observed a similar kind of response of Mo thin film deposited at different working pressure.

![Graph showing optical reflectivity of Mo thin films at different working pressures](image)

**Fig. 3.4** The optical reflectivity of Mo thin films at different working pressures indicates that due to the improvement in the surface uniformity at lower working pressure viz. 1 mTorr, the surface scattering reduces and the reflectivity improves.

### 3.4 EFFECT OF RF POWER

#### 3.4.1 Structural Characterization

After observing better structural, optical, and electrical properties of the Mo thin film grown at 1 mTorr working pressure, the RF power was varied from 60 to 100 W by keeping the working pressure constant at 1 mTorr. The XRD spectra of Mo thin films grown at different powers keeping the Working pressure at 1 mTorr are shown in Fig. 3.5.
Fig. 3.5 The XRD analysis of the Mo thin films grown at different RF power by keeping the working pressure constant at 1 mTorr. At 100 W RF power and 1 mTorr working pressure, the negligible shift in the 2θ angle from its bulk value, 40.05°, this shows that a minimum strain is present in the Mo thin film.

The XRD spectra shown in Fig. 3.5 indicate a preferred orientation along the (110) plane and observed d-values matches with the JCPDS data card 01-1208. 2θ angle shift to a lower angle for the Mo film grown at lower RF power indicates the strain, and therefore, the stress introduced in the film. In addition, by reducing the RF power, the FWHM increases, which indicates that the crystalline size reduces to 8.47 nm due to the lower kinetic energy of the sputtered particles hence lower deposition rate. Table 3.2 shows the 2θ value of the (110) plane, its corresponding d-value, crystalline size, lattice constant, percentage of strain, and the estimated stress of Mo thin films grown at different RF power by keeping the Working pressure constant at 1 mTorr.
Table 3.2 The $2\theta$ value of the (110) plane, its corresponding d-value, crystalline size, lattice constant, strain, and estimated stress of Mo thin films grown at different RF power by keeping the working pressure constant at 1 mTorr.

<table>
<thead>
<tr>
<th>RF power (W)</th>
<th>d-value (Å)</th>
<th>$2\theta$ (degree)</th>
<th>Crystalline size, D (nm)</th>
<th>Lattice constant, $a$, (nm)</th>
<th>Strain (%)</th>
<th>Stress ($\times 10^{-9}$ Nm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>2.22174</td>
<td>40.572</td>
<td>14.32</td>
<td>0.314</td>
<td>0.1562</td>
<td>0.88</td>
</tr>
<tr>
<td>80</td>
<td>2.24344</td>
<td>40.163</td>
<td>14.06</td>
<td>0.317</td>
<td>0.8100</td>
<td>-4.5</td>
</tr>
<tr>
<td>60</td>
<td>2.27387</td>
<td>39.603</td>
<td>8.47</td>
<td>0.321</td>
<td>2.1800</td>
<td>-12.29</td>
</tr>
</tbody>
</table>

By reducing the RF power from 100 W to 60 W, the deposition rate decreases from $\sim$0.32 to $\sim$0.28 nm/s respectively. Due to the reduced scattering of the sputtered atoms at lower power, at 60 W, with the gas atoms, the crystallinity degrades. Thus, the strain in the Mo film increases. At higher RF power (100 W) due to the increase in the deposition rate, $\sim$0.32 nm/s, the crystallinity of the film improves and the strain reduces.

### 3.4.2 Morphological Characterization

The AFM morphology of Mo thin films grown at 1 mTorr working pressure and different RF powers viz. from 60 W to 100 W is shown in Fig. 3.6. At lower RF power, viz. 60 W, due to the lower deposition rate the grain growth is not uniform. The surface roughness of Mo thin films is 3.45 nm for 60 W RF power. As the RF power increases from 60 W to 100 W, the deposition rate increases, which leads to the improvement in the uniform grain growth and so, the surface roughness improves and reach to the 7.78 nm.

### 3.4.3 Electrical and Optical Characterization

The sheet-resistance of Mo thin film decreases as the RF power decreases. The sheet-resistance mainly depends on the surface morphology of the film. The AFM results confirm that the porosity increases as the RF power reduces from 100 W to 60 W, which increases the sheet-resistance of the Mo thin film shown in Fig. 3.7. At 1 mTorr working pressure and 100 W RF power we got the minimum sheet-resistance viz. $\sim$1 $\Omega$/square.
Fig. 3.6 The AFM images of Mo thin film at different RF power, by keeping the working pressure 1 mTorr, indicate that by increasing the RF power the film surface becomes dense and relatively uniform due to the increase in the deposition rate.

Fig. 3.7 - The sheet-resistance of Mo thin films deposited at different RF power by keeping the working pressure constant at 1 mTorr. At higher power the films shows a lower sheet-resistance because of the dense grain structure of the film.
Fig. 3.8 - The optical reflectivity of Mo thin films grown at different RF power, by keeping a constant Working pressure at 1 mTorr, suggests that at a relatively higher RF power, due to a uniform surface structure, the reflectivity is higher compared with that at other RF power.

In the optical reflectivity, here, by reducing the RF power, the columnar crystallites isolates, observed from the AFM images, which reduces the optical reflectance shown in Fig. 3.8. Owing to a uniform distribution in the grains, the Mo thin film grown at 100 W RF power shows a higher reflectance (~ 55 %).

3.5 LASER SCRIBING OF MOLYBDENUM THIN FILM

The first step in manufacture of thin film solar cell is the deposition of molybdenum (Mo) as a 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 arise with a heat-affected zone around the scribed area due to the laser pulse beam [56]. 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 [57]. To increase the solar cell efficiency, the scribing of Mo layers desire minimum scribed area to have maximum active solar cell area [58] and so, minimize the dead area in the cell. Optimum operation for thin-film PV materials has been investigated by several PV manufacturers [59, 60, 61].
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.

**Scribe Quality**

However, the good 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 are 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 lose 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.

In order to achieve a 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. 3.9. Some calculations were made in order to establish the geometrical situation [62] during the laser pulse.

![Fig. 3.9 Geometrical representation of exposed area.](image)

Given that the laser spot has a radius, \( R \), and is repeated with a frequency, \( f \), 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. 3.9). This area can be considered as the area of film removed per pulse [63].
\[ A = \pi R^2 - \frac{R^2}{2} \arccos \left( \frac{\Delta y}{2R} \right) - \frac{\Delta y}{2} \sqrt{R^2 - \frac{\Delta y^2}{4}} \]  

(3.4)

where \( \Delta y \) is the distance between consecutive pulse centres.

\[ \Delta y = \nu \times \frac{1}{f} \]  

(3.5)

**Laser Scribing Process and Parameters**

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). 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 3.3. In our study we have kept the scribing speed constant at 500 mm/s in order to achieve fine 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 film shows different kind of scribe pattern. The smoothness of the scribed was observed using a polarization microscope (LABOURLUX 11, Leitz).

<table>
<thead>
<tr>
<th>Laser</th>
<th>Multi Diode Pump Fiber Laser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal average power</td>
<td>20 W (optional 10 W)</td>
</tr>
<tr>
<td>Maximum peak power</td>
<td>&gt;7.5 Kw</td>
</tr>
<tr>
<td>Power tunability</td>
<td>10 - 100%</td>
</tr>
<tr>
<td>Pulse repetation rate</td>
<td>20 - 80 KHz</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1060 ± 10 nm</td>
</tr>
<tr>
<td>Pulse duration@20 kHz</td>
<td>&lt;120 ns</td>
</tr>
<tr>
<td>Power stability</td>
<td>&gt;95 %</td>
</tr>
<tr>
<td>Pulse energy@20 kHz</td>
<td>1 mJ</td>
</tr>
<tr>
<td>Beam quality</td>
<td>1.5 (M^2)</td>
</tr>
<tr>
<td>Output beam diameter (1/e^2)</td>
<td>9 mm</td>
</tr>
<tr>
<td>Scribe speed</td>
<td>upto 1000 mm/s</td>
</tr>
<tr>
<td>Inbuilt guide (marking) laser</td>
<td>He-Ne laser (660 nm and 0.5 mW)</td>
</tr>
</tbody>
</table>
Optimization of Minimum Scribe Line Width

The scribed line width, which is an important parameter in the patterning of the semiconductor single- or multi-layers, is mainly dependent on laser power and pulse frequency. Laser power varies in this study from 20 W to 2 W and the pulse frequency varies from 1 Hz to 80 Hz. Figure 3.10 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 width of the scribed line was near to 80 μm.

![Graph showing the variation of scribe line width with pulse frequency](image)

Fig. 3.10 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 patterning the different semiconductor devices. From Fig. 3.10, 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. 3.11 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.

Figure 3.11 show 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 scribed the different thickness of Mo thin films at 2 W laser power and 1 Hz pulse frequency and got a 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, as shown in Fig. 3.12.

At low power (2 W) and low frequency (1 Hz) we have achieve the minimum scribe line width i.e. 40 µm (Fig. 3.12 (a)). 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. 3.12 (b). 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 3.13.
Fig. 3.12 Scribed line thickness 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).
The obtained exposed area (scribe line width) of the scribe line of different thickness of the Mo thin films is shown in Fig. 3.14. On increasing the thickness of the Mo thin films, we see from the Fig. 3.14, that the scribe line width decreases. At 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 $\mu$m was obtain (Fig. 3.14 (h)). The maximum scribe line width, i.e. 220 $\mu$m, with poor scribe area is observed at 60 nm thin Mo films (Fig. 3.14 (a)).
Fig. 3.14 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 1 Hz laser pulse frequency.
3.6 CONCLUSIONS

The Mo thin films were grown on soda lime glass substrate using RF magnetron sputtering system for its use as a back-contact in the CIGS thin film solar cell. The significant influence of Working pressure and the RF power was observed by the structural, morphological, electrical, and optical studies. The observations indicate that the metallic Mo thin films showed a better crystallinity, morphology, conductivity, and reflectivity at a lower working pressure (1 mTorr) and a higher RF power (100 W). The Mo thin film grown at 100 W RF power and 1 mTorr working pressure shows a sheet-resistance of $\sim 1 \ \Omega/\square$ surface roughness of 7.78 nm and near to 55 % reflectivity in the visible region. Apart from the growth of Mo thin film the laser scribing also performed which will use in future in the solar cells module preparation. Different thicknesses (60 nm to 800 nm) of Mo thin films were used for the laser scribing. Laser parameters have been determined that provide reproducible, good scribes, that do not present any unwanted bridges.