Low Divergence atomic beam using laser ablation of thin film

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ABSTRACT

This paper reports the formation of low energy low divergence pulsed indium atomic beam via ablation of thin film by illumination from the rear side with second harmonic of Q switched Nd:YAG laser under high vacuum (~10^{-5} Torr). Angular divergence of ablated indium beam was measured for the different laser powers. Ablation dynamic and longitudinal atomic velocity was studied as a function of laser energy per pulse.

Keywords: Pulsed indium atomic beam, Laser ablation, Ablation dynamics.

1. INTRODUCTION

Generation of collimated atomic beams is a topic of interest because of its importance in the field of atom optics\(^1\)-\(^2\), laser spectroscopy\(^3\) and in the fabrication of optoelectronics devices\(^4\). The most general method for the production of atomic beam is thermal oven. The divergence of atomic beam produced by thermal ovens is very large. The limitation on the collimation of atomic beam is mainly due to the geometry of the oven itself. Collimation of the beam is performed with the help of appropriate set of apertures and finally via laser cooling\(^5\). Application of thermal oven is restricted to the materials of low melting points only. There have been reports\(^6\)-\(^8\) on the generation of neutral atomic beam using laser ablation of thin films. The advantage of laser ablation over the thermal oven system for the production of neutral atomic beam is manifold. It can be used for any material irrespective of their melting points. It has ability to produce high atomic flux with energies ranging from cold to super-thermal range. In the earlier reports\(^6\)-\(^7\) normally laser is focused from the rear side onto the thin films of the material resulting into the ablation of material from the thin film, giving atomic beam. Because of the focusing of the laser beam, the momentum distribution and hence the divergence of the resulting atomic beam is large and the collimation is required for precision application viz micro/nano lithography.

In this paper the formation of low divergence and low energy atomic beam via laser ablation is reported. The experiments was performed by illuminating thin film of indium from the rear side by unfocused high power Q switched Nd:YAG laser (2\(^{nd}\) harmonic, 532 nm). The divergence of the atomic beam is much less in this case as compared to that of the focused laser beam. The divergence of atomic beam can be further curtailed by introducing an aperture in the path of ablated beam. The effect of laser power on the divergence, velocity of atomic beam and the ablation dynamics is also reported. The divergence of atomic beam with focused and unfocused laser beam is also compared.

2. EXPERIMENTAL DETAILS

The experimental set-up for the formation of indium atomic beam is as shown in fig.1.

![Figure 1: Experimental set-up for the formation of neutral atomic beam of indium.](image_url)
The thin films of indium were illuminated from the rear side directly (unfocused) by second harmonic of Q switched Nd:YAG laser (400 mJ in fundamental, 8 ns pulse width, beam diameter 8 mm, model HYL101 Quanta System) under high vacuum (~10^{-5} Torr). Thin film was kept slightly slanted to incoming laser beam to avoid retro-reflection of laser beam going back into the laser head. During the experiment, thin film was move vertically via motorized feed-through to get the fresh region of thin film for ablation for each shot. A glass substrate was kept few centimeters apart from the thin film to deposit the indium atomic beam for the divergence measurement. This experiment was conducted and repeated for different laser energies. The experiment was also conducted by placing an aperture having 0.35 cm diameter in between the target and the substrate to curtail the divergence further. The effect of focused laser beam onto the divergence was studied by focusing the laser onto the target film with a 35 cm focal length lens from the rear side.

Experimental set-up for the study of ablation dynamics of indium thin film and measurement of longitudinal velocity of indium atomic beam is shown in fig.2. For the measurement of longitudinal velocity, He-Ne laser 1 was aligned parallel to the thin film through one of the window of the ablation chamber and detected by a photodiode 1 (PD 1) placed at the opposite window. As a result of the production of pulsed atomic beam via rear side laser (Nd:YAG) illumination of thin film, He-Ne laser 1 gets deflected and accordingly the photodiode signal undergoes modulation and is recorded onto the Tektronix TDS 2012 Digital Storage Oscilloscope (DSO). The He-Ne laser 1 and PD 1 were moved simultaneously along the direction of propagation of atomic beam and the deflection signals were recorded at different distances from the target. By measuring the peak position of the deflected signal for the known distances from the target, velocity of propagation of the beam was measured as a function of laser energy.

Figure 2: Experimental set-up for the study of ablation dynamics and the measurement of longitudinal velocity of atomic beam. GP1 and GP2 are glass plates and PD’s (1-3) are photodiodes.

For recording the ablation dynamics, a second He-Ne laser 2 was launched from the other window so as to illuminate the target film at 45°. The reflected beam was detected with PD 2 kept at 90° window with respect to that of He-Ne laser 2. As a result of ablation, reflectivity of the thin film changes, hence the intensity of the He-Ne laser 2 falling on PD 2 changes and is displayed onto the DSO. The DSO was used in the single shot acquisition mode and was triggered with Nd:YAG laser. For this 4% of 4% reflection from the two microscopic glass plates GP1 and GP2 was taken as shown in fig.2 onto PD 3 and was fed onto DSO for the trigger as well as for reference signal. All the PD’s (1-3) were terminated with 50 Ω terminator.
3. RESULTS AND DISCUSSION

Figure 3: Photo showing ablated indium thin film (T) by Nd:YAG laser at 122 mJ energy per pulse and deposited indium on the glass substrate (S1 and S2).

Figure 3 shows the ablated target of indium thin film (T) and the indium thin film formed by depositing the ablated material onto the glass substrates (S1 and S2). As the target T was moved vertically, therefore on illumination with Nd:YAG laser continuously (10 pps), the material of the thin film was ablated from the target resulting into the region of transparent strip of width almost equal to the size of the laser beam (~8 mm diameter). The deposited central region of S1 and S2 have lesser density than outer portion, this is due to ablation of material from this region by the Nd:YAG laser which comes out from the ablated portion of the target (T). The divergence of atomic beam was estimated by measuring the diameter of the deposited spot (from S), the width of the ablated strip (from T) and the distance between the target and the substrate. The results of divergence measurement for unfocused and focused laser beam and with and without aperture are listed in Table 1. The divergence of atomic beam is found to increase with the laser energy and is about two orders of magnitude less than that of produced with focused laser. The presence of aperture curtails the wings of the atomic beam, thereby further reducing the divergence down to 88 mrad at 122 mJ of laser energy per pulse.

<table>
<thead>
<tr>
<th>No.</th>
<th>Laser energy per pulse (mJ)</th>
<th>Average Angular Divergence with unfocused laser and without aperture (mrad)</th>
<th>Average Angular Divergence with aperture (aperture diameter = 0.35 cm) (mrad)</th>
<th>Average Angular Divergence with focused laser (rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>122</td>
<td>237</td>
<td>88</td>
<td>23</td>
</tr>
<tr>
<td>2</td>
<td>85</td>
<td>81</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>43.5</td>
<td>23</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1: Comparison of angular divergence values at different laser powers, with/without apertures and with unfocused/focused laser beam.

Time of flight measurement using the beam deflection set-up was used for velocity measurement of the atomic beam. The oscilloscope traces, recorded for beam deflection set-up at various distances are shown in Fig. 4. The trace 1 of Fig. 4 (PD 3) corresponds to the Nd:YAG signal and used as a reference signal as well as for the trigger. Traces 2 to 7 of Fig. 4 correspond to the signal from beam deflection set-up (PD 1) at distances from 1 mm to 6 mm from the target respectively. The average velocity of the atomic beam measured as a function of laser energy is listed in Table 2. The indium beam velocity measured was 43.9 m/s corresponding to laser energy of 43.5 mJ per pulse. The velocity was found to increase up to 122 mJ of laser energy. Above this energy, no significant change in the velocity was observed.
Signals from PD 2 for the reflectivity measurement during the ablation process are shown in fig. 5. Trace 1 corresponds to the PD 3 signal and trace 2 is from PD 2 for the reflectivity measurement. The beginning of PD 2 signal increases abruptly because of the scattered Nd:YAG laser falling onto it and then slowly decays and goes down with respect to the dc level (corresponding to the unablated film). The percentage changes in reflectivity of thin films are also listed in table 2. The percentage change in reflectivity is large for higher laser energies. From the oscilloscope traces it is obvious that ablation process is fast for higher laser energies.

Figure 5: Changes in thin film reflectivity due to ablation at laser energy per pulse (a) 122 mJ, (b) 85 mJ and (c) 43.5 mJ laser energy per pulse. Trace 1 and 2 are from PD 3 and PD 2 respectively.

<table>
<thead>
<tr>
<th>No.</th>
<th>Laser energy per pulse (mJ)</th>
<th>Average Longitudinal velocity of atoms (m/s)</th>
<th>Percentage reflectivity change of thin film during ablation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>122</td>
<td>95.7</td>
<td>6 µs required to reduce the reflectivity of thin film by 61%</td>
</tr>
<tr>
<td>2</td>
<td>85</td>
<td>46.6</td>
<td>5 µs required to reduce the reflectivity of thin film by 57%</td>
</tr>
<tr>
<td>3</td>
<td>43.5</td>
<td>43.9</td>
<td>2.5 µs required to reduce reflectivity of thin film by 9%</td>
</tr>
</tbody>
</table>

Table 2: Results of time of flight measurement and ablation dynamics
X-ray diffraction pattern (XRD) of indium thin film, produce by depositing ablated material onto the glass substrate is shown in fig.6. The XRD pattern matches with standard reference given in the literature\textsuperscript{9}.

![XRD pattern of indium thin film](image1)

Figure 6: XRD pattern of indium thin film produced by catching the ablated material on the glass substrate.

Indium thin film produced by depositing ablated material onto the glass substrate was scanned by atomic force microscope (Nanoscope E Digital Instrument Contact mode) for surface morphology studies and the scan picture is shown in fig.7. 100-450 nm size lumps can be seen in the picture. Note that this thin film was formed due to multiple deposition of the ablated material.

![AFM scan picture of indium thin film](image2)

Figure 7: AFM scan picture of indium thin film produced by depositing the ablated material on the glass.

4. CONCLUSION

The technique of laser ablation was used to produce low divergence low energy indium atomic beam. Results show that the divergence as low as 23 mrad can be achieved with this technique without using any apertures. With the help of apertures, divergence of atomic beam can be further curtailed. It was found that divergence of atomic beam increases with laser energy. Ablation dynamics of the thin film was studied as a function of laser energy and it was found that at 43.5 mJ laser energy per pulse the ablation rate is quite slower than that of at 85 and 122 mJ. Longitudinal velocity of
atomic beam was measured as a function of laser energy and it was found that atomic beam slows down at 85 and 43.5 mJ laser energy per pulse as compared to that of at 122 mJ.

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REFERENCES


