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LASER FOCUSING OF CHROMIUM ATOMS

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Abstract: Atom lithography can be used to fabricate regular nanoscale pattern on a substrate with high resolution and large area. Because the pitch of the grating is traceable to absolute atomic frequency, it has potential to be used as nanoscale pitch standards. The researches on laser focusing chromium in national institute of metrology are reported in this paper. Chromium wire array with a pitch of λ/2 and a height of 1 nm has been deposited on InP substrate.

Keywords: Atom lithography, Chromium, Laser focusing, Nanoscale pitch, Calibration.

1. INTRODUCTION

With the rapid growth of nanoindustry and nanotechnology, the instruments for nanoscale length measurement has been used widely in various fields. The fabrication of the standards for calibrating these instruments has become an important topic.

Atom lithography is a technique which is used to fabricate nanostructure whose pitch can be referenced to atomic transition. In contrast with other nanostructure manufacture techniques, such as electron beam lithography and ion beam lithography etc., atom lithography is a parallel process that can construct regular pattern with high resolution and large area in a short time. Furthermore, atom lithography has special meaning to nanoscale dimension metrology because the pitch of the grating is traceable to absolute atom frequency directly.

The major difference of atom lithography with ordinary optical lithography is that the role between lights and atoms is interchanged. In atom lithography, laser is used as the masks, mirrors or lens in optical lithography, and the atoms are used as light. Because de Broglie wavelength of atom is only a few picometres, the resolution of the grating is almost not limited by diffraction effects.

Atom lithography has two branches. One is known as the atoms direct deposition in which the nanostructure is piled up on a substrate by the atoms focused by laser mask [1]. In the other case, no force is presented on atoms. The substrate is covered by a resist known as self-aessembled monolayer (SAM), which is only sensitive to metastable atoms. The atoms in the metastable state are pumped to the ground state except at the position where the light intensity is very small. Then the laser mask can be used as a absorption mask. The patterns formed on the resist layer can be transferred to the substrate by a subsequent etch step [2].

The simplest pattern produced by atom lithography is the one dimensional lines array. Its principle is shown in Fig. 1. Atomic steam sprayed from an oven. Then it is collimated by laser cooling to reduce its angle. After that, the collimated atomic beam pass through a standing wave vertically. The frequency of the standing wave always shift several MHz away from the transition of the atom. With the dipole force, which is proportional to the intensity gradient, atoms move toward the node or the peak of the standing wave, depending on whether the laser frequency is below or above the nature atomic resonance frequency. The standing wave can be looked as a lens array and the atomic beam acts as a light beam. Therefore, the distance between two adjacent lines is half one wavelength.

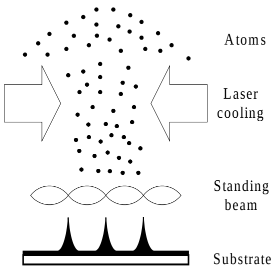

Fig. 1 Schematic principle of laser focusing

So far, there are more kinds of nanostructures fabricated by laser focusing than that of absorb methode. Laser focusing is firstly demonstrated by Timp et al. with Na atoms [3]. They obtained the lines array with a pitch of λ/2. McClelland et al. applied Cr atoms to this technique successfully at NIST [4]. This is a significant advance since the structure is stable at ambient conditions. The pitch accuracy is investigated, showing a relative uncertainty of 2.3×10^{-5} or an average pitch of (212.7777±0.0069) nm is achieved [5]. Therefore, they concluded that laser focused atomic deposition has potential as a means of fabricating nanometer-scale pitch standards.

Because the frequencies of the lasers used to focusing various atoms are different, the pitches deposited by different materials, such as Al (λ/2, 155 nm) [6, 7], Fe (λ/2, 186 nm) [8, 9], Yb (λ/2, 200 nm) [10] are different. Besides these, many kinds of pitches such as λ/8 [11], 2λ/3, λ/√3 [12], λ/√2 [13], has been fabricated by more complex laser mask.

In this paper, we will present the laser focusing chromium atoms in National Institute of Metrology (NIM). The experimental setup is described and the results of deposition are demonstrated.

2. LASER FOCUSING CHROMIUM ATOMS AT NATIONAL INSTITUTE OF METROLOGY

The experimental setup for chromium atoms deposition we developed is shown in Fig. 2. The laser source is constit of a pump laser (Verdi-10, Coherent, 532 nm), a single-frequency Ti:S laser (MBR-110, Coherent, 851 nm) and a resonant frequency doubler (MBD-200, Coherent, 425.5 nm). The 425.5 nm laser is splitted to four beams by several pairs of λ/2 waveplates and polarizing beam splitters (PBS). All of these four beams are perpendicular to the atomic beam. The leftmost one is used for fluorescence induced frequency stabilization, which is used to restrain the frequency fluctuation of the 425.5 nm laser to less than 0.5 MHz. The second beam is shaped to about 24 mm × 2 mm to collimate the chromium beam by Doppler cooling. On the left side of the cooling laser a square aperture is used to reduce the collimation angle mechanically. A laser cooled collimation angle of 0.6 mrad was measured by using of the knife edge technique presented in [14]. The third beam is the standing wave for focusing atoms. Its frequency is shifted by a acousto-optic modulator to below the atomic resonace about 200 MHz. The rightmost one is a probe beam to survey the state of the atomic beam collimation.

The chromium atoms deposite in a vacuum of 10^{-5} Pa. An ultra flat substrate is mounted on the flat reflector which is used to form the cooling and the focusing laser field in the vacuum. The surface of the substrate is perpendicular to the atomic beam, too. A setup for measuring and adjusting the micro-distance between the standing wave and the substrate (not shown in Fig. 2) is designed and applied. The distance between the standing wave and the substrate is one radium of the beam.

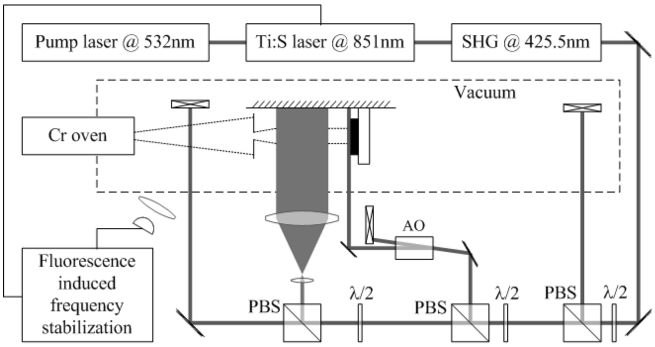

Fig. 2 Schematic diagram of the chromium atom deposition in NIM.

3. RESULTS AND CONCLUSION

The oven temperature is 1900 K. The power of the cooling laser and the standing wave are 46 mW and 30 mW respectively. The $1/e^2$ radius of the standing wave is about 360 μm. To construct an ideal standing wave field, the waist of the third beam should as close as possible to the flat reflector. The vacuum degree in the chamber is less than 5×10^{-5} Pa. The deposition time is 180 min.

The nanostructure was grown on an InP wafer which is cut into 15 mm × 4 mm × 0.4 mm. Its surface roughness is no more than 0.5 nm. To image the samples we used an atomic force microscope (AFM, Dimension Icon, Veeco). The deposition region was scanned using tapping mode and the 2D and 3D images with a size of 2 μm × 2 μm are shown in Fig. 3. The pitch is (212.8±0.5) nm and the height of the deposited line is about 1 nm. This nanostructure covers a 0.5 mm by 1 mm area of the substrate.

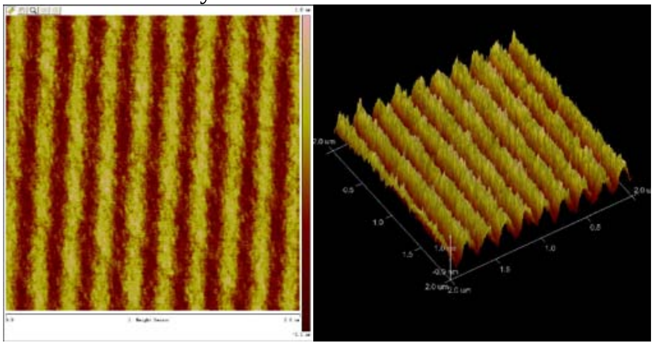

Fig. 3 Atomic force microscope images of the chromium atom deposited on a InP substrate, left: 2D image, right: 3D image.

The major problem we should have to solve is how to increase the deposition rate. We measured the deposition rate without the laser focusing, showing that it is as slow as about 1/10 deposition rate reported by other groups. The reason that causes the low atomic flux may be the jam of the atom source. And we think that the slow deposition rate causes the low height of the lines.

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