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Pitch standards via laser-focused deposition

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As electronic and magnetic devices continue to become smaller, the need for fabricating structures on the nanometer scale grows larger. We are currently exploring the techniques of atom optics to fabricate structures on the nanometer scale. Atom optics treats neutral atoms, which can have extremely small de Broglie wavelengths, in an analogous way to light beams or charged particle beams. In atom optics, "optical elements" such as lenses, mirrors and beamsplitters are used to manipulate the atoms' trajectories. Optical forces can be either dissipative in nature, in which case they can cool, collimate and/or intensify an atom beam [1], or conservative, in which case they can serve as a lens [2]. Nanostructures created by laser-focusing of atoms possess the potential of being an extremely accurate length standard on the submicron scale.

In our experiments we use the dissipative spontaneous force to collimate a beam of chromium atoms and the conservative dipole force to focus the atoms into an array of lines as they deposit onto a Si substrate [3]. The dipole force arises from the interaction of the induced dipole in an atom with the gradient in the laser intensity. The intensity variation in the standing wave acts as a series of cylindrical lenses, spaced by $\lambda/2$, which can focus atoms in the nodes (antinodes), when the laser frequency is tuned above (below) the atomic resonance. The first demonstration of laser focused atomic deposition was by Timp *et al.*, using sodium [4].

Figure 1 shows the experimental arrangement consisting of an effusive source of chromium atoms, a pre-collimating aperture, a region of optical collimation and a substrate mounted facing the atomic beam. A single-frequency dye laser provides a few hundred mW of laser light for both the optical collimation and the standing wave. The dye laser is tuned 10 MHz below the atomic resonance to collimate the atomic beam and 500 MHz above the atomic resonance for focusing the atoms. The frequency of the dye laser is calibrated against a chromium saturated absorption cell with an accuracy of 1 MHz.

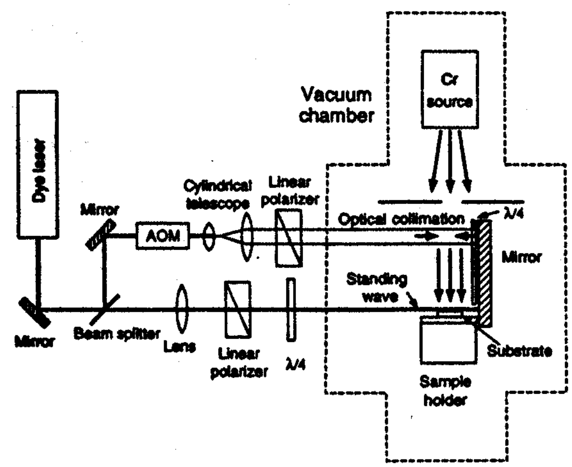

Figure 1. Schematic of laser focused atomic deposition apparatus.

The standing wave laser, with $1/e^2$ diameter 0.4 mm, grazes across the sample so as to generate a half-Gaussian intensity distribution with maximum at the surface of the substrate. Figure 2 shows an atomic force micrograph of a section of the chromium lines created by deposition through the standing wave. The laser wavelength fixes the spacing between the lines at 212.78 nm. Lines extend over the entire region covered by the laser beams. The linewidth is measured to be 65 ± 6 nm and the height of the structures is 34 ± 10 nm.

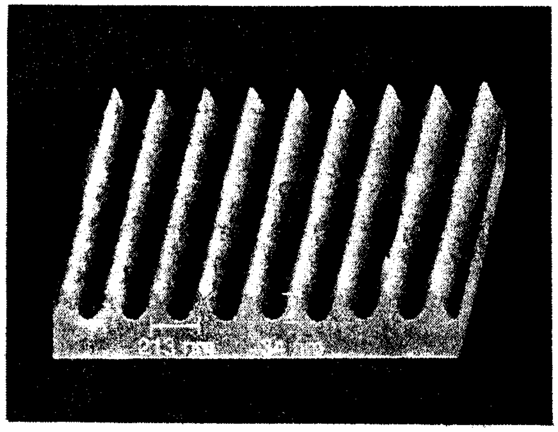

Figure 2. AFM image of Cr lines created by laser focused atomic deposition.

The structures have the potential of being an extremely accurate pitch standard for calibration of microscopes (e.g. AFM and SEM) on the submicron scale since the spacing between the lines is determined solely by the periodicity of the interference pattern created by the laser light. The lines are extremely uniform over 0.2 mm^2 area and therefore they can be used for calibration purposes in a large field of view. The artifacts are made by deposition of Cr and are stable in air and thus portable.

The accuracy of the spacing between the lines is determined by the laser wavelength and the angle between the standing wave mirror and the incident laser light. Since the laser light is provided by a single frequency dye laser locked to an atomic resonance, the wavelength is determined by spectroscopic techniques with a precision of a part in 10^6. The misalignment between the standing wave mirror normal and the incident laser beam is a small perturbation because the pitch changes with the cosine of this angle, which is quadratic near 0°.

We have also done preliminary experiments to generate two dimensional patterns through the superposition of two standing waves at right angles. Such a configuration produces either an array of crossed perpendicular lines or spots depending on the laser frequency and polarization and the spacing is still determined by the interference pattern of the light field.

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