# Novel Light Fields For Atomic Manipulation

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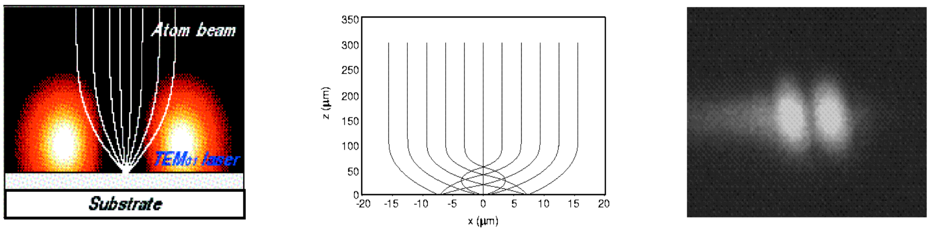
The field of atom optics has inspired an extraordinary level of interest in recent years. The properties of atoms, such as their very small deBroglie wavelengths, their complex internal structure, and their relatively high mass make them a valuable tool for lithography, nanofabrication, and the study of fundamental quantum and gravitational effects.

In atom optics, atoms are manipulated in a way similar to the control of light in conventional optics. This manipulation may be achieved by exploiting the dipole force, which acts along the intensity gradient of near-resonant light-fields. Using slow atoms dramatically increases the interaction time between the atoms and the light-field. The attempt to manipulate such slow atomic beams in a controlled way depends on the ability to create useful light-fields.

Early attempts at focussing atoms utilised standing waves. These fields have strong intensity gradients, and have been used to deposit simple atomic patterns such as lines [1], dots [2] and hexagons [3]. For the purposes of atom lithography, the creation of more complex patterns is of interest. Such patterns could be created by scanning a focussed beam of atoms across a substrate, or by sending slow atoms through a complex light field. We consider the creation of such complex light-fields through the use of computer generated optical elements (CGOE) [4]. CGOEs can be used to modify either the phase or the amplitude of an incident light-field (typically a gaussian field) and thus to produce a new, preferred light-field. For the purposes of atomic manipulation, our initial interest is in creating lenses for atoms. Such lenses could be achieved using $TEM_{01}$ and $TEM_{01}^*$ fields, both of which have a dark central region into which slow atoms can be focussed (fig. 1(a) and (b)).

A $TEM_{01}$ field (fig. 1(c)) is produced by introducing a $\pi$ phase shift between the upper and lower halves of a gaussian beam, or with a diffractive element. For $TEM_{01}^*$ fields, a spiral phase mask can be used to introduce the appropriate phase shift into the incident field.

The fabrication of CGOEs can be approached in a number of ways. Early techniques involved the reduction of a computer generated pattern into a photographic emulsion [5]. High resolution can be achieved using electron-beam lithography or laser-writing techniques [6], which involve the exposure of a resist, followed by chemical etching. Methods designed to reduce or remove the necessity of etching have also been investigated [7]. Spatial light modulators allow rapid production and modification of kinoforms [8]. We will report on holograms created by direct laser ablation of a substrate patterned using a series of commercially produced chromium on silica masks. Devices for creating $TEM_{01}$ fields will be demonstrated and the possibilities for




(a) (b) (c)

Figure 1: (a) Schematic showing atoms entering a $TEM_{01}$ field
(b) Two-dimensional trajectories in a plane along the atomic beam axis for a $Rb^{87}$ beam entering a $TEM_{01}$ field. Longitudinal atomic velocity is 17m/s, peak laser intensity is $I_0 = 9.0 \times 10^8 W/m^2$, laser detuning is 200MHz.
(c) $TEM_{01}$ field output from a diffractive element created using laser ablation.

$TEM_{01}{}^*$ fields will be described. The generation of more complex light fields relies on the ability to calculate appropriate CGOEs. Iterative approaches to this calculation will be presented (fig. 2).

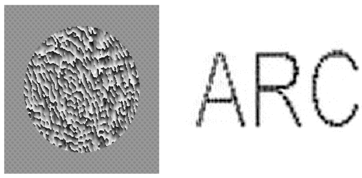



Figure 2: Phase map for a CGOE (left) and resultant field calculated iteratively (right).

**Acknowledgments.**
We gratefully acknowledge the support of the Australian Research Council and the *Ernst and Grace Matthaei Scholarship* (T.R.M.).

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