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13. ABSTRACT (Maximum 200 words)

Methods for position measurement of moving atoms with ultrahigh spatial resolution have been developed, based on resonance imaging in a spatially varying potential with a steep gradient. Using a spatially light-shift due to an off-resonant focused optical field, spatial resolution of 200 nanometers, with a few percent linearity over several microns has been obtained. Centroids of narrow spatial features, which are created and probed in the experiments, are determined with an accuracy of  $\pm 20$  nanometers. Ultimately, with higher gradients and single atom detection, uncertainty principle limited spatial resolution of a few nanometers will be attainable. These methods will have novel applications in the characterization of atom-optical elements, and in the development of new methods of ultrahigh resolution neutral atom lithography.

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J.E.Thomas  
 G. R. Welch (Postdoctoral Associate)  
 L.-J. Wang (Postdoctoral Associate)  
 J. R. Gardner (Graduate Student, Ph. D. received, May, 1993.)  
 M. Marable (Graduate Student)  
 T. Savard (Graduate Student)

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## BRIEF OUTLINE OF RESEARCH FINDINGS

During the period of this research, we have investigated, for the first time, the application of resonance imaging in very large potential gradients to measure the position of moving atoms in beams with extremely high spatial resolution. Briefly, the method employs Raman transitions between two long lived sublevels of the atomic ground state of  $^{152}\text{Sm}$ . The initial atomic state is populated while the final atomic state is initially emptied by optical pumping. A potential with a large gradient along one axis,  $x$ , shifts the energy of the final state and therefore correlates the resonance frequency of the Raman transition with the atomic position. If an atom makes a transition to the final state, it must have been located near the point where the transition frequency is tuned into resonance with the applied Raman fields. Atoms which make a transition to the final state are subsequently detected by resonance fluorescence. Hence, a plot of the resonance fluorescence intensity versus the Raman transition frequency yields the spatial distribution along the  $x$  axis for atoms in the initial state.

Experiments were performed first with a magnetic field gradient which spatially tuned the Raman transition frequency at a rate of  $10^9$  Hz/cm. This experiment yielded a spatial resolution (Half width at  $1/e$ ) of 1.7 microns. This resolution is in excellent agreement with the ideal value predicted for the potential gradient and atomic beam collimation employed in the experiments. Later experiments employed a spatially varying light-shift of the Raman transition frequency. This was generated with a 1 cm diameter laser beam focused with a cylindrical lens, so that a tight focus was achieved perpendicular to the atomic beam. In this case, a spatial tuning rate of  $1.16 \times 10^{10}$  Hz/cm was achieved and suboptical wavelength spatial resolution of 200 nanometers, with a few percent linearity over several microns was obtained. Centroids of narrow atomic spatial distributions, which were created and measured in the experiments, were determined with  $\pm 20$  nanometer accuracy. Again, the ultimate spatial resolution obtained is in excellent agreement with the ideal value predicted for the conditions of the experiments.

Ultimately, it is expected that with single atom detection and still larger potential gradients, uncertainty principle limited spatial resolution of a few nanometers can be obtained using the resonance imaging method.

In addition to these experiments, new experiments have been started which investigate the use of resonance imaging in a magnetic field gradient to characterize

the spatial patterns created in an atomic interferometer. Ultimately, it is expected that the resonance imaging method will play an important role in characterizing atom-optical elements.

### *Technological Applications*

Optical manipulation of atomic wavefronts currently is being explored as a means of direct writing neutral atom lithography by a number of groups in this country and abroad. The suboptical wavelength atom imaging methods which have been developed as a primary part of this research will be important for a variety of applications to novel microfabrication methods including:

- i) characterization of neutral atom beams which are transversely cooled and focussed by optical methods.
- ii) development of "adaptive" atom optics based on position dependent depletion of atomic wavefronts- on a suboptical wavelength scale.
- iii) development of suboptical wavelength scale "position dependent chemistry," by combining state selective chemical reactions with techniques of state selective atomic localization.

In addition to these applications, it has been suggested to us recently that the Raman induced resonance imaging method may be important for measuring spatial correlations in flowing systems. In a supersonic atomic beam, for example, the last collision which occurs for pairs of atoms just before exiting the nozzle region leaves them highly correlated. Long range collisions apparently play an important role, and these are usually neglected in treatments of the flow. The resonance imaging methods which we are developing may permit measuring position distributions in flowing systems with high spatial resolution and without disturbing the flow.

## PUBLICATIONS

1. G. R. Welch, K. D. Stokes, C. Schnurr, J. Gardner, and J. E. Thomas, "Uncertainty Limited Atomic Position Measurement using Optical Fields," Symposium on Atomic Optics, Annual Meeting of the Optical Society of America, Boston, MA, November, 1990.
2. G. R. Welch, K. D. Stokes, J. Gardner, M. Marable, C. Schnurr, and J. E. Thomas, "Precision Atomic Position Measurement using Optical Fields: Building Heisenberg's Microscope," *Quantum Electronics and Laser Science Technical Digest Series*, **11**, (Quantum Electronics and Laser Science, Baltimore, Md., 1991), p. 26, invited talk.
3. K. D. Stokes, C. Schnurr, J. R. Gardner, M. Marable, G. R. Welch, and J. E. Thomas, "Precision Atomic Position Measurement using Optical Fields," *Phys. Rev. Lett.* **67**, 1997 (1991).
4. J. E. Thomas, "Precision Atomic Position Measurement and Localization using Optical Fields," *Bull. Am. Phys. Soc.* **37**, 1145 (1992), invited talk.
5. G. R. Welch, K. D. Stokes, J. Gardner, M. Marable, C. Schnurr, and J. E. Thomas, "High Resolution Atomic Position Measurement," *Quantum Electronics and Laser Science Technical Digest Series*, **13**, 2 (1992), invited talk.
6. J. R. Gardner, M. L. Marable, G. R. Welch, and J. E. Thomas, "Suboptical Wavelength Imaging of Moving Atoms in a Light-Shift Gradient," *Quantum Electronics and Laser Science Technical Digest Series*, **12**, 20, (1993).
7. J. R. Gardner, M. L. Marable, G. R. Welch, and J. E. Thomas, "Suboptical Wavelength Position Measurement of Moving Atoms using Optical Fields," *Phys. Rev. Lett.* **70**, 3404 (1993).
8. J. R. Gardner, M. L. Marable, G. R. Welch, and J. E. Thomas, "Suboptical Wavelength Position Measurement of Moving Atoms in a Light-shift Gradient," Eleventh International Conference on Laser Spectroscopy, (Hot Springs, VA, June 13-18, 1993).