tion-intensive because of the number of spatial and energy coordinates involved. Therefore, parallel distributed computing is imperative: the software that implements the model distributes the computations, energy-wise, to the various processors. Initial simulations were performed using, variously, between 16 and 64 processors of an SGI Origin multiprocessor computer. The figure presents an example of results of one set of simulations.

Scanning Miniature Microscopes Without Lenses

Polarization-sensitive and multicolor versions should also be possible.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure schematically depicts some alternative designs of proposed compact, lightweight optoelectronic microscopes that would contain no lenses and would generate magnified video images of specimens. Microscopes of this type were described previously in "Miniature Microscope Without Lenses" (NPO-20218), *NASA Tech Briefs*, Vol. 22, No. 8 (August 1998), page 43 and "Reflective Variants of Miniature Microscope Without Lenses" (NPO20610), *NASA Tech Briefs*, Vol. 26, No. 9 (September 1999), page 6a. To recapitulate: In the design and construction of a microscope of this type, the focusing optics of a conventional microscope are replaced by a combination of a microchannel filter and a charge-coupled-device (CCD) image detector. Elimination of focusing optics reduces the size and weight of the instrument and eliminates the need for the time-consuming focusing operation.

The microscopes described in the cited prior articles contained two-dimensional CCDs registered with two-dimensional arrays of microchannels and, as such, were designed to produce full two-dimensional images, without need for scanning. The microscopes of the present proposal would contain one-dimensional (line image) CCDs registered with linear arrays of microchannels. In the operation of such a microscope, one would scan a specimen along a line perpendicular to the array axis (in other words, one would scan in "pushbroom" fashion). One could then synthesize a full two-dimensional image of the specimen from the line-image data acquired at one-pixel increments of position along the scan.

In one of the proposed microscopes, a beam of unpolarized light for illuminating the specimen would enter from the side. This light would be reflected down onto the specimen by a nonpolarizing beam splitter attached to the microchannels at their lower ends. A portion of the light incident on the specimen would be reflected upward, through the beam splitter and along the microchannels, to form an image on the CCD.

If the nonpolarizing beam splitter were replaced by a polarizing one, then the specimen would be illuminated by s-polarized light. Upon reflection from the specimen, some of the s-polarized light would become p-polarized. Only the p-polarized light would contribute to the image on
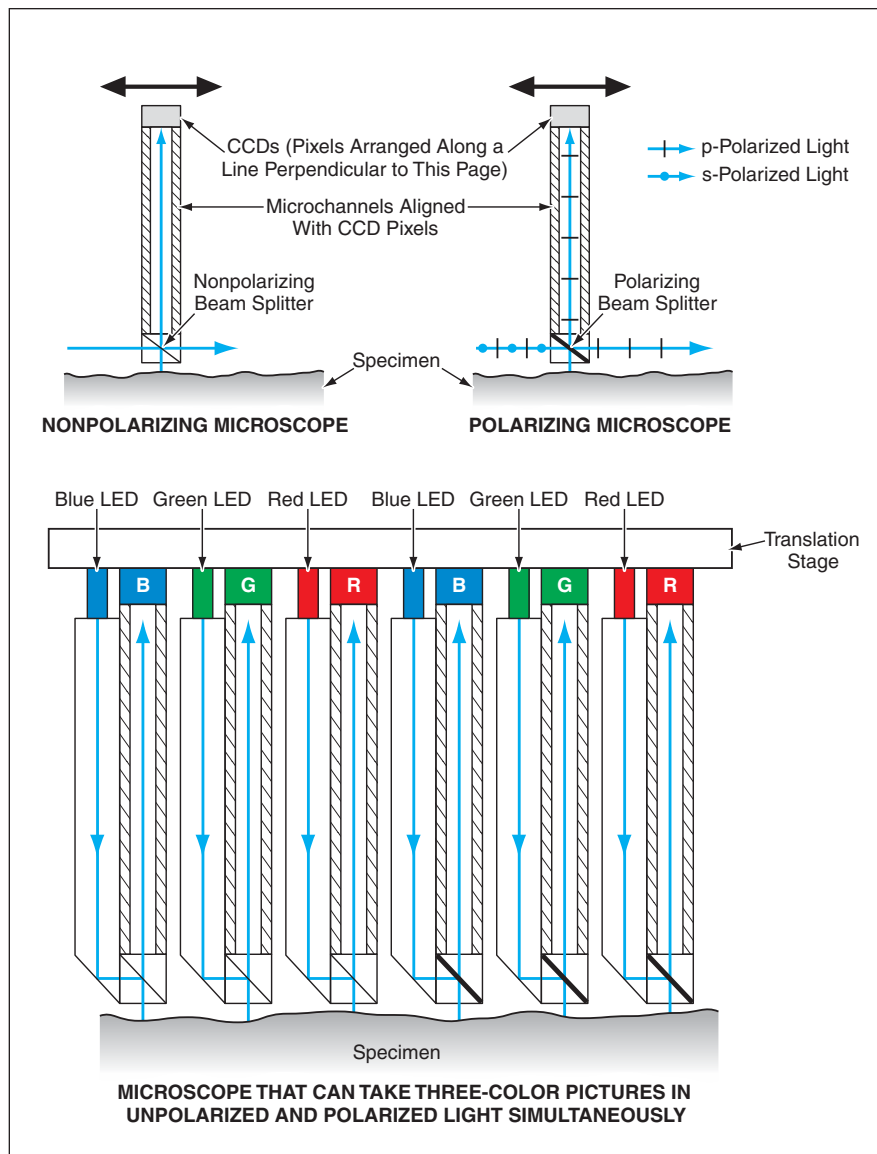
Scanning Lensless Microscopes of various degrees of complexity and capability would be made from line-imaging CCDs, the pixels of which would be aligned with microchannels.

the CCD; in other words, the image would contain information on the polarization-rotating characteristic of the specimen.

The scanning microscopes described above could be used as building blocks for a multicolor, multipolarization microscope. In the example shown in the figure, six scanning microscopes would be assembled on a single translation stage. The microchannels would be interspersed with light sources that would comprise light-emitting diodes (LEDs) coupled to the beam splitters via prismlike light guides.

This work was done by Yu Wang of Caltech for NASA's Jet Propulsion Laboratory.

# Manipulating Neutral Atoms in Chip-Based Magnetic Traps

Magnetic-field gradients are used to accelerate and decelerate atoms.

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Several techniques for manipulating neutral atoms (more precisely, ultracold clouds of neutral atoms) in chip-based magnetic traps and atomic waveguides have been demonstrated. Such traps and waveguides are promising components of future quantum sensors that would offer sensitivities much greater than those of conventional sensors. Potential applications include gyroscopy and basic research in physical phenomena that involve gravitational and/or electromagnetic fields. The developed techniques make it possible to control atoms with greater versatility and dexterity than were previously possible and, hence, can be expected to contribute to the value of chip-based magnetic traps and atomic waveguides.

The basic principle of these techniques is to control gradient magnetic fields with suitable timing so as to alter a trap to exert position-, velocity-, and/or time-dependent forces on atoms in the trap to obtain desired effects (see figure). The trap magnetic fields are generated by controlled electric currents flowing in both macroscopic off-chip electromagnet coils and microscopic wires on the surface of the chip.

The methods are best explained in terms of examples. Rather than simply allowing atoms to expand freely into an atomic waveguide, one can give them a controllable push by switching on an externally generated or a chip-based gradient magnetic field. This push can increase the speed of the atoms, typically from about 5 to about 20 cm/s. Applying a non-linear magnetic-field gradient exerts different forces on atoms in different positions — a phenomenon that one can exploit by introducing a delay between releasing atoms into the waveguide and turning on the magnetic field.
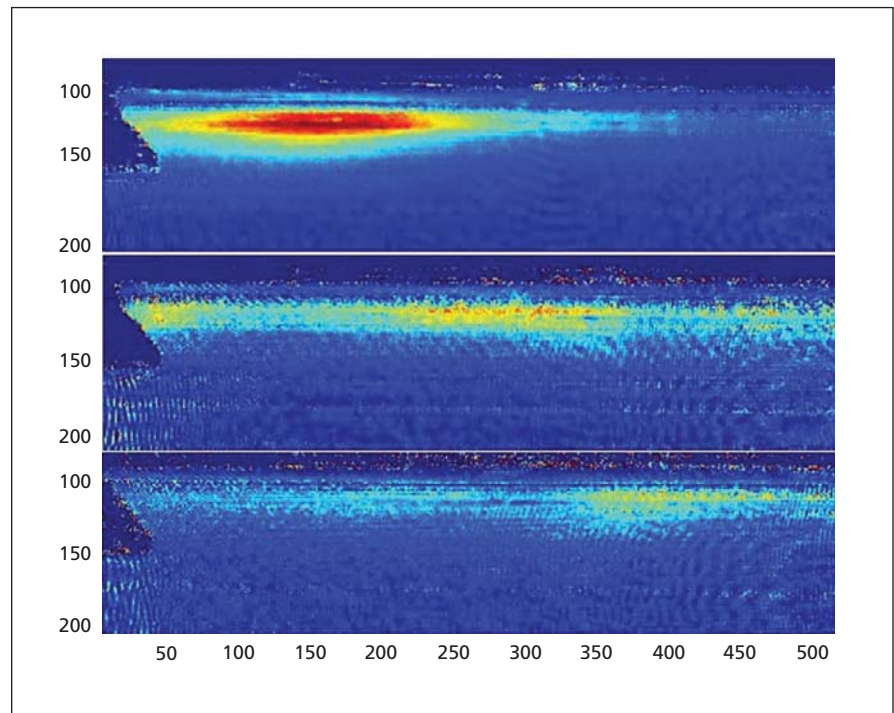
A **Cold Cloud of ^{87}Rb Atoms** is manipulated in an atomic waveguide by use of controlled gradient magnetic fields. This sequence of images shows the cloud moving rightward toward a potential barrier, then splitting into a part that passes through the barrier and a part reflected leftward from the barrier. The numbers on the axes are coordinates in units of 8-μm pixels.

Before the magnetic field is turned on, the fastest atoms move away from the region where the gradient will be the strongest, while the slower atoms lag behind, remaining in that region for a while. Hence, once the magnetic field is turned on, it can be expected to push the slower atoms harder than it will push the faster atoms. By controlling the amplitude and delay of the gradient, one can tailor the push so as to cause the slower atoms to catch up with the faster ones at a chosen location along the waveguide, thereby effectively focusing the atoms (in other words, greatly increasing the density of the cloud of atoms) at that location. Of course, in addition, the acceleration of the slower atoms effectively raises the temperature of the cloud of atoms. In a proposed variant of this accelerating-and-focusing technique, the gradient would be suitably repositioned along the waveguide and its amplitude and timing suitably altered, so as to preferentially decelerate the faster atoms, thereby effectively cooling the cloud of atoms.

This work was done by David Aveline, Robert Thompson, Nathan Lundblad, Lute Maleki, Nan Yu, and James Kohel of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).
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