symmetry-induced degeneracy problem is to make the atoms non-spherical.

The figure shows a practical, new,[6] faced-centered-cubic structure that simultaneously solved the two outstanding problems in photonic structure: (1) In this new geometry, the atoms are non-spherical, distorted along $<111>$, lifting the degeneracy at the W-point of the Brillouin Zone and permitting a full photonic bandgap rather than a pseudogap. (2) Furthermore, this fully three-dimensional fcc structure lends itself readily to micro-fabrication on the scale of optical wavelengths. It is created by simply drilling three sets of holes 35.26° off vertical into the top surface of a solid slab or wafer, as can be done for example by reactive ion etching. At refractive index $n<3.6$, typical of semiconductors, the 3-D forbidden photonic bandgap width, calculated and measured, is <20% of its center frequency. Calculations indicate that the gap remains open for refractive indices $n \gtrsim 2$.

If the $<111>$ distortion is severe enough, the result is diamond structure,[7] which appears to give the widest photonic bandgaps of all. However, diamond structure is difficult to micro-fabricate. It requires three additional drilling directions in addition to those shown in the figure, all in the plane of the slab.

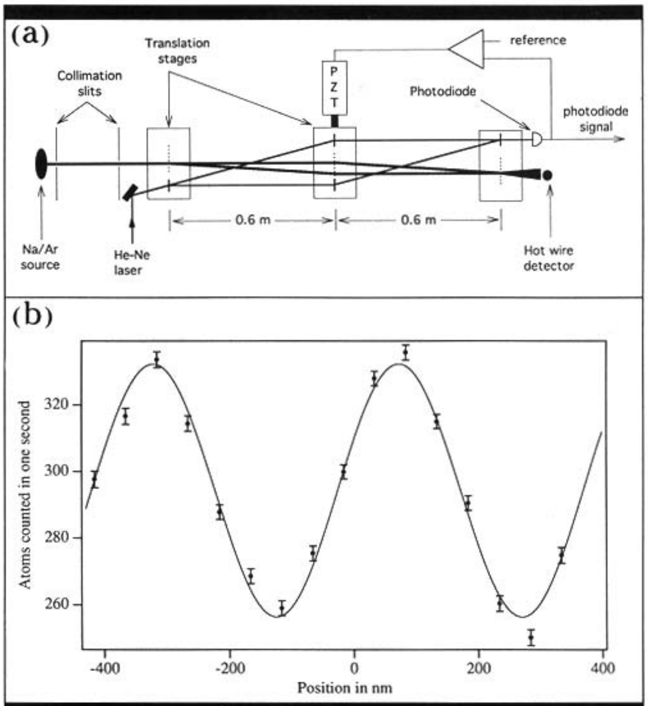
REFERENCES

1. E. Yablonovitch, "Inhibited spontaneous emission in solid-state physics and electronics," Phys. Rev. Lett. **58**, 1987, 2059-2062; S. John, "Strong localization of photons in certain disordered dielectric superlattices," Phys. Rev. Lett. **58**, 1987, 2486-2849.
2. J. Maddox, "Photonic bandgaps bite the dust," Nature **348**, 1990, 481.
3. E. Yablonovitch and T.J. Gmitter, "Photonic band structure: The face-centered cubic case," Phys. Rev. Lett. **63**, 1989, 1950-1953.
4. K.M. Leung and Y.F. Liu, "Full vector wave calculation of photonic band structure in face-centered cubic dielectric media," Phys. Rev. Lett. **65**, 1990, 2646-2649.
5. Z. Zhang and S. Satpathy, "Electromagnetic wave propagation in periodic structures: Bloch wave solution of Maxwell's equations," Phys. Rev. Lett. **65**, 1990, 2650-2653.
6. E. Yablonovitch and K.M. Leung, "Photonic bandgaps," Nature **351**, 1991, 278.
7. K.M. Ho *et al.*, "Existence of a photonic gap in periodic dielectric structures," Phys. Rev. Lett. **65**, 1990, 3152-3155.

ATOM INTERFEROMETERS

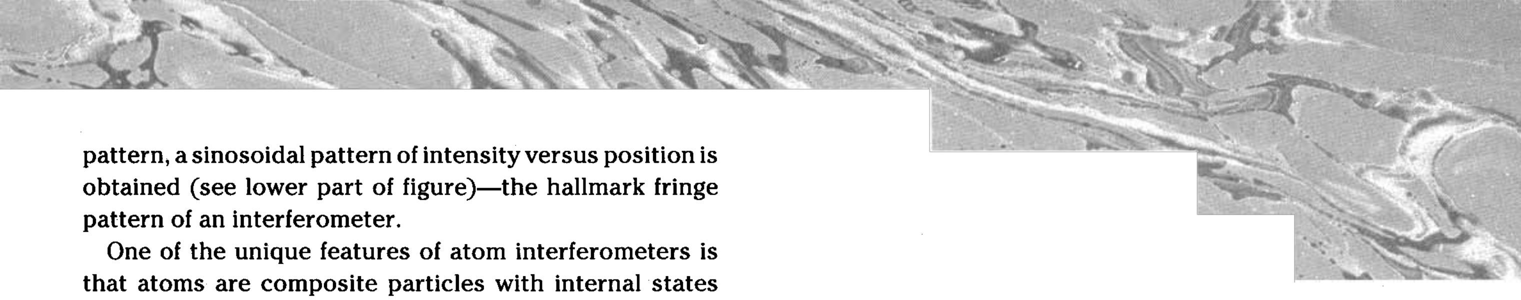
BY DAVID PRITCHARD, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Years of discussions about possible ways to make atom interometers bore fruit this year as several groups demonstrated different experimental routes to the realization of a working atom interferometer. These realizations built on advances in atom slowing and trapping, the manipulation of atoms using light forces, and the construction of nanofabricated structures for diffracting atoms.[1] These advances culminated this year in the use of nanofabrication technology by a group in Konstanz, Germany,[2] to realize Young's experiment for He atoms, in which atoms displayed interference fringes as a result of passing through a double slit.



(a) Schematic of the MIT interferometer (not to scale) showing the active vibration isolation and position control system (laser interferometer). The 0.4 μm-period atom gratings are indicated by a vertical dashed line, the 3.3 μm-period optical gratings by a vertical solid line. (b) Interference signal from 400 seconds of data (~23 seconds per point). Background hot wire noise of 40 cps subtracted. The solid line is a least squares fit to a sine function with 400 nm period. Error bars are one standard deviation assuming Poissonian noise, and slightly underestimate the noise.

A group at MIT has used three transmission gratings to build an interferometer for Na atoms.[3] In this design (see figure), which has previously been realized for both photons and neutrons, the first grating diffracts a collimated beam of atoms into several beams separated from each other by the diffraction angle. The second grating is located far enough downstream so that these beams are spatially separated, and is positioned to intercept two of the beams and diffract them in new directions, so that they will converge. Further downstream, these two beams overlap spatially, producing a standing wave with crests and valleys aligned perpendicularly to the direction of propagation of the atom beams. According to the postulates of quantum mechanics, these crests and valleys represent regions of high and low probability for detection atoms. These are detected by translating a third grating across this standing wave pattern; since the grating bars and openings have the same period as the standing wave



pattern, a sinosoidal pattern of intensity versus position is obtained (see lower part of figure)—the hallmark fringe pattern of an interferometer.

One of the unique features of atom interferometers is that atoms are composite particles with internal states whose lifetimes allow the atom to exist for some time in a superposition state. When laser light is used to create such superpositions, it may impart different momenta to the two states[4] so that they travel in different directions—thus, the spectroscopic interaction with the laser is a de facto beam splitter. Two recent atom interferometers have been based on this idea, employing either a suitable spatial array[5] or temporal pulse sequence[6] of such interactions to separate and recombine the atoms. In these interferometers, the fringes are observed as an oscillation of the final state of the atom that depends on the differential phase accumulated between the two paths.

These light-based devices have already demonstrated an important application of atom interferometers: the measurement of inertial effects such as rotation, acceleration, and gravity. The predicted Sagnac rotation was observed in Ref. 5, and sensitivity to gravitational acceleration at the 3×10^{-6} level was demonstrated in Ref. 6. Another area of application will be fundamental physics: tests of quântum mechanics such as the Aharonov-Casher effect,[7] measurement of the equality of proton and electron charges, and a precise measurement of the momentum of a photon. Interferometers for atoms, and also for molecules, will offer more accurate ways to measure intrinsic properties of these particles, like their polarizability. They will also open up new areas of study, such as measurements of the index of refraction of a gas for a particle beam that passes through it.

The future of atom interferometers looks bright. Atom beam sources are inexpensive and intense relative to other particle beams/sources (*e.g.*, neutrons, electrons), several techniques have now been demonstrated to make interferometers for them, and the atoms that may be used in them come with a wide range of parameters such as polarizability, mass, and magnetic moment. This assures the applicability of these instruments to a wide range of measurements of both fundamental and practical interest.

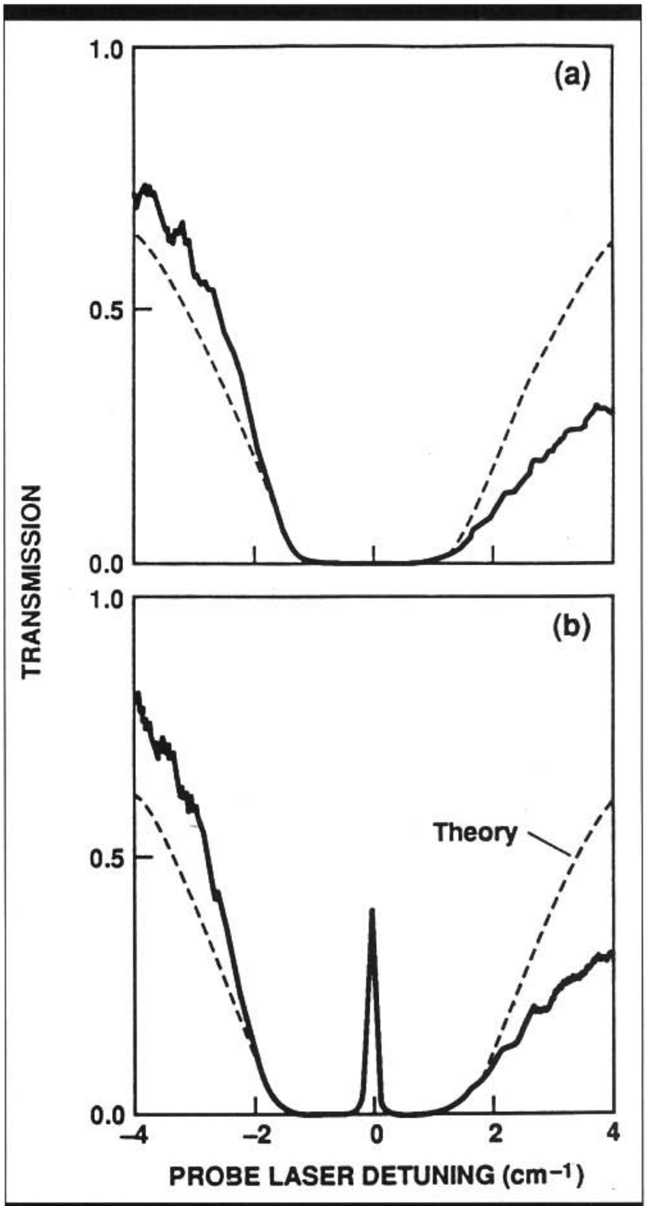
REFERENCES

1. D.E. Pritchard, "Atom gratings and guides," Opt. News **14:12**, 1988, 7-8.
2. O. Carnal and J. Mlynek, "Young's double slit experiment with atoms: A simple atom interferometer," Phys. Rev. Lett. **66**, 1991, 2689-2692.
3. D.W. Keith *et al.*, "An interferometer for atoms," Phys. Rev. Lett. **66**, 1991, 2693-2696.
4. C.J. Borde "Atomic interferometry with internal state labelling," Phys. Lett. **140**, 1989, 10-12.
5. F. Riehle *et al.*, "Optical Ramsey spectroscopy in a rotating frame: Sagnac effect in a matter wave interferometer," Phys. Rev. Lett. **67**, 1991, 177-180.
6. M. Kasevich and S. Chu, "Atomic interferometry using stimulated Raman transitions," Phys. Rev. Lett. **67**, 1991, 181-184.
7. Y. Aharonov and A. Casher, "Topological quantum effects for neutral particles," Phys. Rev. Lett. **53**, 1984, 319-321.

ELECTROMAGNETICALLY INDUCED TRANSPARENCY

BY S.E. HARRIS, STANFORD UNIVERSITY

For about 15 years, the atomic physics community has been aware of a phenomena that is termed population trapping.[1] When two lasers with frequencies that couple



TRANSMISSION VS. PROBE LASER DETUNING FOR (a) Ω_{23}=0 AND (b) Ω_{23} = 1.3 CM-1. Ω_{23} IS THE RABI FREQUENCY OF THE COUPLING LASER.