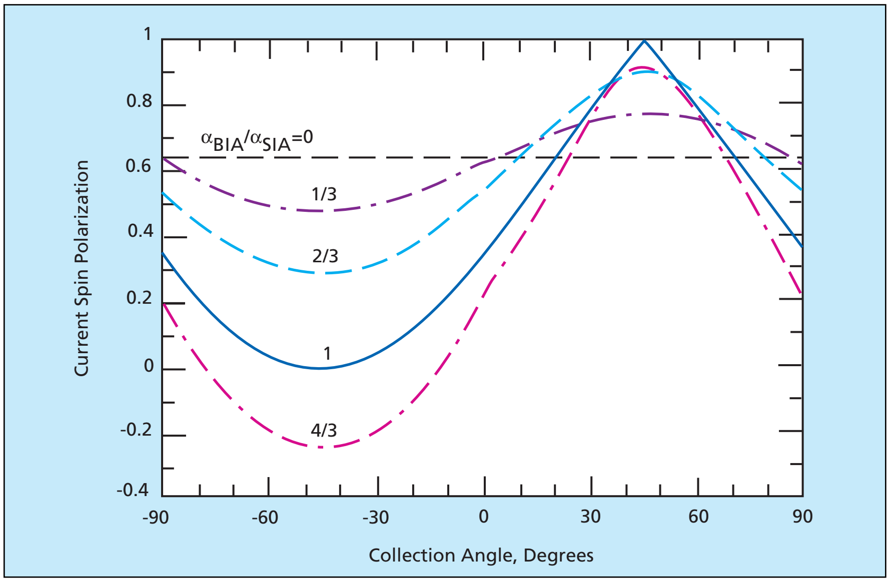


Current Spin Polarization was computed as a function of collection angle for different values of the ratio between the BIA and SIA coefficients ($\alpha_{BIA}/\alpha_{SIA}$), under the simplifying assumption of perfect subband filtering.

ber. In a spin filter, the spin-polarized currents produced by the Rashba effect would be extracted by quantum-mechanical resonant tunneling.

The origin of the enhancement now proposed lies in recognition that not only the SIA but also bulk inversion asymmetry (BIA) contributes to the spin-dependent energy splitting. The conceptual device structure on which the proposal is based is a spin-filtering resonant tunneling heterostructure, grown along the [001] direction (the z axis), that includes an asymmetric quantum well. The physics of this structure was represented by a simplified two-band, spin-dependent Hamiltonian model. This model was chosen because although it is only approximate, its simplicity facilitates understanding of how BIA could be utilized to enhance spin filtering.

The theoretical calculations were performed using this model. It was found that when only SIA is taken into account, the theoretical upper limit of current spin polarization for a Rashba-effect resonant tunneling spin filter with a one-sided spin collector can be expected to be 2/π (about 63.7 percent), independent of the direction of the collector. When BIA was taken into account along with SIA, it was found that current spin polarization could be changed from the SIA-only value by varying the collection angle: in particular, the greatest and least polarization values were found to occur in the [110] and $[1\bar{1}0]$ directions, representing collection angles of +45° and -45°, respectively.

This work was done by David Ting and Xavier Cartoixa of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-40210

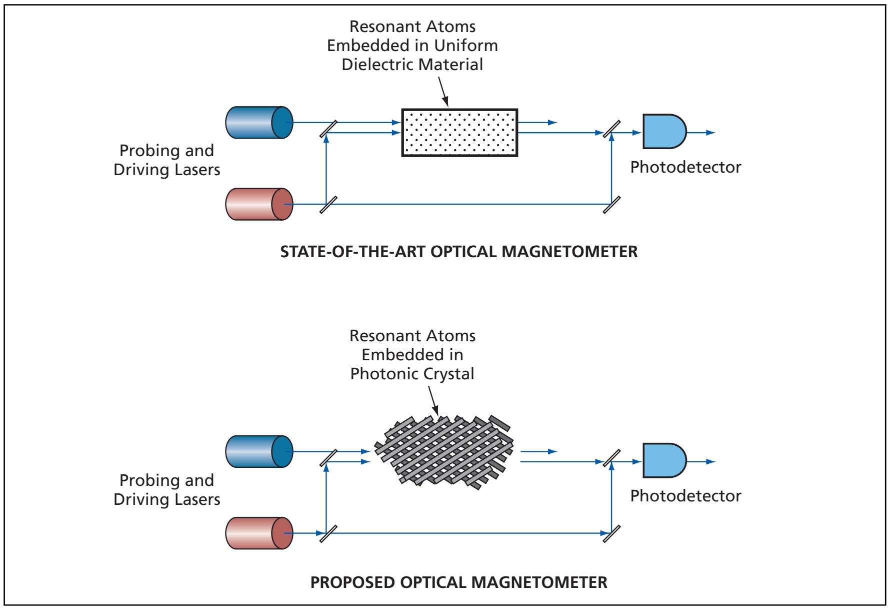
Optical Magnetometer Incorporating Photonic Crystals

Sensitivity would be increased by orders of magnitude.

NASA's Jet Propulsion Laboratory, Pasadena, California

According to a proposal, photonic crystals would be used to greatly increase the sensitivities of optical magnetometers that are already regarded as ultrasensitive. The proposal applies, more specifically, to a state-of-the-art type of quantum coherent magnetometer that exploits the electromagnetically-induced-transparency (EIT) method for determining a small change in a magnetic field indirectly via measurement of the shift, induced by that change, in the hyperfine levels of resonant atoms exposed to the field.

One of the key components of a magnetometer of this type is a collection of the aforesaid resonant atoms, which have an energy spectrum that is sensitive to any variation in magnetic field. These atoms are placed in a cell, wherein they are irradiated with light from a quantum source (see figure), such that the interactions between the light and the atoms produce a beam of coherent or entangled photons suitable for use in determining the magnetic



An **Optical EIT Magnetometer** according to the proposal would be based on the same measurement principle as that of a state-of-the-art optical EIT magnetometer, but the resonant atoms would be embedded in a photonic crystal such that the variation in the index of refraction with magnetic field would be greatly increased.

field in the cell. If the conditions under which the atoms are exposed are those of EIT, then the shift of Zeeman sublevels of the atoms caused by a change in the magnetic field results in a change in the index of refraction of the region containing the atoms. The change in the index of refraction is measured by means of a Mach-Zehnder optical interferometer. Then the change in the magnetic field can be computed from the known relationship between the magnetic field and the index of refraction.

A photonic crystal is an engineered periodic dielectric structure that can be tailored by design to exhibit one or more of a rich variety of optical properties. Notable among these properties is a range of photon energies, known as the photonic band gap (PBG), in which light cannot propagate. In an optical EIT magnetometer according to the proposal, sensitivity would be increased by using a photonic crystal to control and enhance the interaction between the resonant atoms and the optical beam. A cloud of the resonant atoms would be embedded in a photonic crystal rather than in a uniform dielectric material in a cell as in a state-of-the-art optical EIT magnetometer of prior design. The photonic crystal would be designed so that the photon frequency at the edge of the PBG would closely approximate the atomic transition frequency. In the PBG-edge region, the variation of the index of refraction with a change in the magnetic field would be orders of magnitude greater than in the absence of the photonic crystal.

This work was done by Igor Kulikov and Lucia Florescu of Caltech for NASA's Jet Propulsion Laboratory. For further information, contact iaoffice@jpl.nasa.gov.
NPO-43802

WGM-Resonator/Tapered-Waveguide White-Light Sensor Optics

Light patterns formed by these optics contain information on absorption spectra.

NASA's Jet Propulsion Laboratory, Pasadena, California

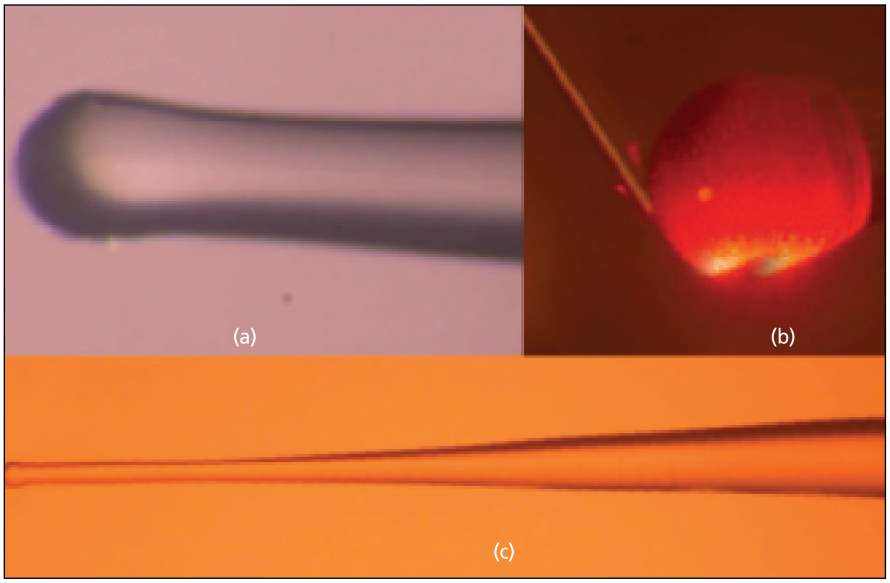
Theoretical and experimental investigations have demonstrated the feasibility of compact white-light sensor optics consisting of unitary combinations of (1) low-profile whispering-gallery-mode (WGM) resonators and (2) tapered rod optical waveguides. These sensors are highly wavelength-dispersive and are expected to be especially useful in biochemical applications for measuring absorption spectra of liquids.

These sensor optics exploit the properties of a special class of non-diffracting light beams that are denoted Bessel beams because their amplitudes are proportional to Bessel functions of the radii from their central axes. High-order Bessel beams can have large values of angular momentum. In a sensor optic of this type, a low-profile WGM resonator that supports modes having large angular momenta is used to generate high-order Bessel beams. As used here, "low-profile" signifies that the WGM resonator is an integral part of the rod optical waveguide but has a radius slightly different from that of the adjacent part(s).

An important difference between such an optic and an ordinary WGM resonator is that its modes decay primarily into Bessel modes of the optical waveguide, rather than to the outside. By changing the dimensions and shape of the WGM resonator and/or the radius of the adjacent part(s) of waveguide, it is possible to change the resonator loading and thereby tailor the degree to which light propagates from the resonator along the waveguide.

The feasibility of applications that involve exploitation of optical waves that have angular momentum depends on the propagation distances of such waves in free space. A high-order Bessel beam that propagates from a WGM resonator along a cylindrical waveguide with evanescent-field coupling cannot leave the waveguide; it propagates to an end of the waveguide, where it is totally internally reflected back along the waveguide toward the other end. However, if the waveguide is tapered, as in an optic of the present type, then the optic acts as radiator horn that preserves the angular momentum of the axially propagating Bessel beams while changing their axial momentum. A notable result of propagation along the taper is that upon reaching the wide end, the Bessel beams can be released into the space outside the waveguide and their shapes are preserved.

An optic of the present type can be made by cutting and polishing a bump/dip toroidal pattern on the side



An **Experimental Optic** of the type described in the text is a unitary structure consisting of a WGM resonator on the narrow end of a tapered fused-silica rod: (a) WGM resonator, (b) coupling light into the WGMs of the resonator using cleaved fiber, and (c) tapered fiber used to release generated Bessel beam into free space.