OPTICAL PHYSICS

Tying knots with light

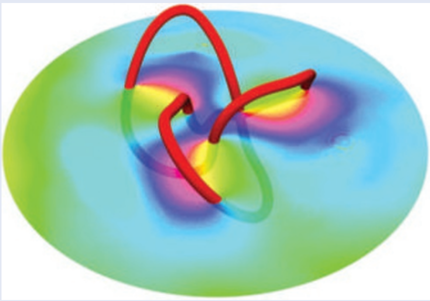
The interaction of multiple light beams in a medium can be thought of as similar to how water flows in a river, with such 'flow' causing the creation of optical vortices — light fields that have characteristic lines of zero intensity in space. Now, using algebraic topology, researchers from the UK have developed a scheme for creating optical vortices in propagating laser fields to form knots and links (*Nature Phys.* **6,** 118–121; 2010).

Mark Dennis and co-workers use mathematical knot theory to construct complex functions in an abstract 3D space on a periodic braid. The knot function is then embedded in a propagating light beam, with the knots forming as dark interference lines from overlapping laser modes.

To experimentally realize the knots, a hologram made by a computer-controlled liquid-crystal display is used to imprint a carefully designed phase pattern of laser light. Observation of the optical knots is possible using a numerical optimization algorithm to increase the contrast in light intensity, making the structures easier to see.

"The technology by which we display the holograms has a limited dynamic range, which in turn makes controlling the dark regions of the beam difficult," the team explained to *Nature Photonics*. Indeed, one objective of the work is to investigate how the beam parameters can be modified such that the required contrast in the hologram is reduced.

The work by Dennis *et al.* shows how physicists can adapt pure mathematics, such as knot theory, for use in physical



ROBERT KING / MARK DENNIS

phenomena. The proposed knot-formation technique may be useful for designing optical landscapes for the blue-detuned trapping of particles or super-resolved fluorescence imaging.

RACHEL WON

YELLOW LASERS

A little diamond goes a long way

The demonstration of a solid-state yellow laser based on diamond could bring new levels of convenience and capability for biomedical applications.

Andrew D. Greentree and Steven Prawer

In the yellow region of the electromagnetic spectrum, at wavelengths around 580 nm, there is a 'dead zone' for solid-state lasers. This gap is important for a number of applications in biomedicine and astronomy, and it is this gap that diamond may be about to fill. Writing in *Optics Letters*, David Spence and his co-workers from Macquarie University in Australia report the first picosecond pulse, mode-locked diamond Raman laser emitting at 573 nm (ref. 1), news that may change the way yellow light is delivered.

Yellow light has several applications, the most obvious being in biomedical physics. The peak absorption wavelength of oxyhaemoglobin — an important oxygen-carrying protein within red blood cells — is around 580 nm (ref. 2), away from the absorption windows of dermatological tissues. This makes yellow-laser-based phototherapies attractive for the treatment of skin complaints because normal tissue is not affected by this wavelength of light. Such therapies have been around since the 1980s and are used to treat conditions such as port-wine stains[3], telangiectasia[4], and psoriasis[5]. Biomedical imaging (either directly or through the two-photon fluorescence of fluorophores) would also benefit from increased spectral coverage[6]. Finally, yellow lasers are useful for exciting the spectral D-lines of sodium, which is important for the generation of laser guide stars (artificial stars created for use in astronomical adaptive optics) by exciting the atmospheric sodium layer at a height of 95 km above the Earth's surface[7].

Although several laser systems that fill the yellow band are commercially available, none represent an ideal solution in terms of cost, convenience or output power. Mainstays of the field are copper–bromide and dye lasers (especially those using rhodamine 6G), but a high-power solid-state candidate remains to be found. Given the importance of solid-state lasers for applications that require high power and high stability, there is currently a race to find a practical and cost-effective solid-state yellow laser. There are a few possible strategies for achieving this. The first is to use semiconductor lasers with intracavity frequency-doubling. A recent study generated 2.1 W of power at 589.15 nm from a frequency-doubled InGaAsN disk laser[8]. An alternative method is to use nonlinear frequency generation, with recent studies demonstrating up to 750 mW of light at 593.5 nm using two laser lines from Nd:YVO_4 and periodically poled KTP[9]. Another approach is to build a Raman laser, and there are several candidates that can be used to achieve this, including $KGd(WO_4)_2$ (ref. 10), $SrWO_4$ (ref. 11) and diamond.

Laser operation requires both a resonator and population inversion on a radiative transition. A Raman laser uses Raman scattering to realize a three-level atomic configuration that can lase when pumped sufficiently hard (Fig. 1a). In a single atom, photons can be absorbed and re-emitted, and this is referred to as scattering. However, in a material, this emission process can also be accompanied by the emission of a phonon — a quantized lattice vibration — and so the emitted photon will be lower in energy. This can be viewed as a three-state 'Λ atom', in which the ground state $|1\rangle$ is the same as the natural ground state; the excited state is a