Prospects for an all-optical remote magnetic field sensor

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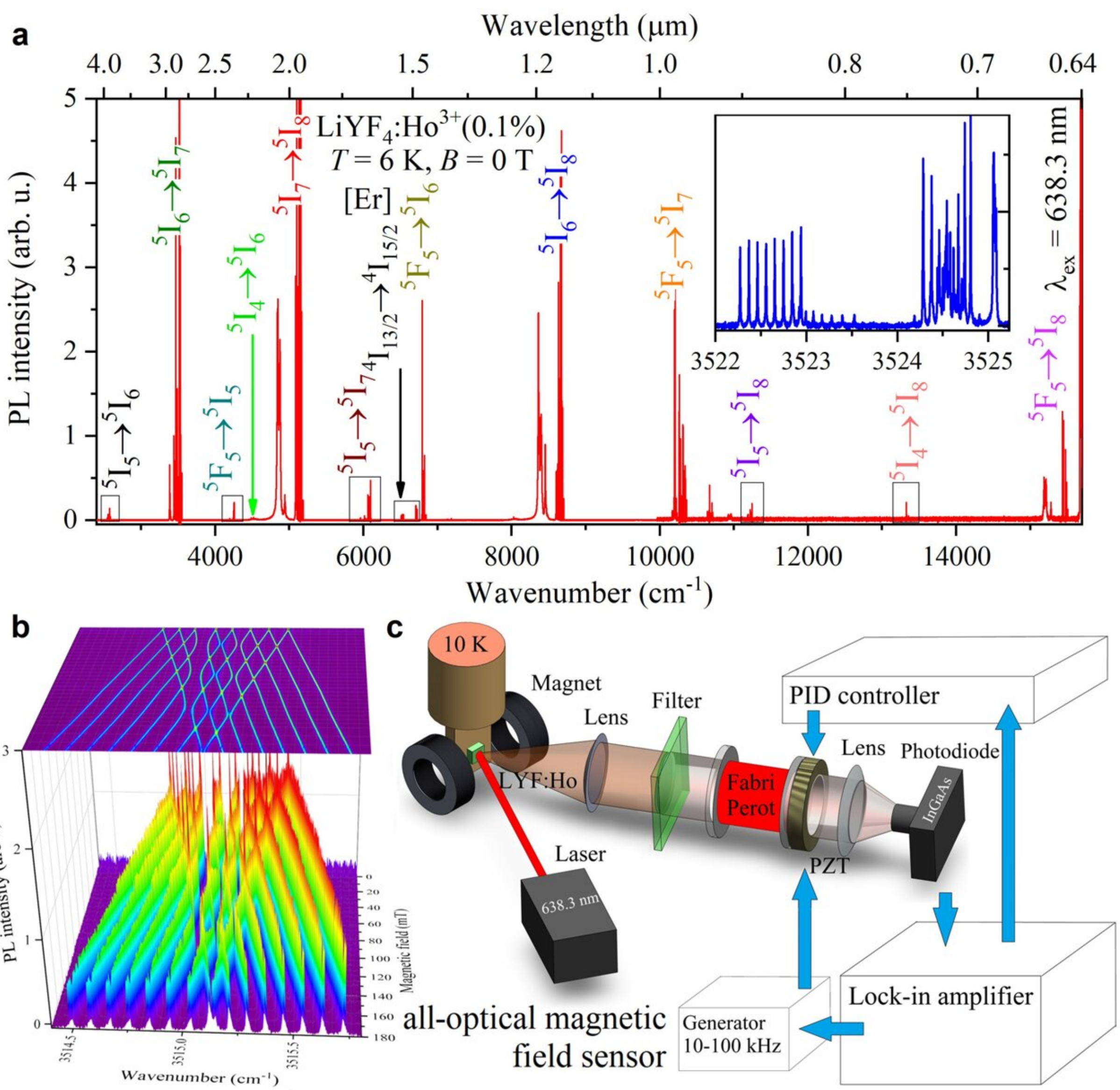

a, broadband low-temperature luminescence spectrum of a lithium yttrium fluoride crystal doped with holmium and a line with hyperfine structure shown in the Inset. b, Splitting of hyperfine components of a luminescent spectral line in a magnetic field. c, A possible scheme of an all-optical magnetic field sensor: the sample placed in a measured magnetic field is illuminated by a diode laser at a wavelength of 638.3 nm; the emission is collected by a lens, filtered and sent to a piezo-scanning Fabry-Perot interferometer, and then to an optical detector; the interferometer scanner and the signal intensity on the diode are connected using feedback through the PID controller and the lock-in amplifier; the scanner displacement will be linearly dependent on the magnetic field applied to the sample. Credit: Boldyrev, K.N., Malkin, B.Z. & Popova, M.N.

Crystals doped with rare-earth (RE) ions exhibit very narrow linewidths of optical transitions. The narrow-line spectra of triply ionized RE elements cover the entire visible and infrared range. RE-doped materials are widely used as laser media, phosphors, scintillators, in solar cells, etc. Nowadays, RE-based luminescence thermometry is successfully developing, demonstrating a wide working temperature range, high thermal sensitivity, and spatial resolution.

In a magnetic field, some spectral lines split, and the magnitude of magnetic field can be determined by measuring this splitting. The narrower the lines, the more accurately the magnetic field can be measured. To carry out remote measurements, it is necessary to use luminescence. The narrowest luminescence lines of crystals doped with rare-earth elements require special high-resolution broadband spectral equipment for their detection and measurement.

In a new paper published in *Light: Science & Applications*, scientists from the Institute of Spectroscopy of the Russian Academy of Sciences have developed a sensitive setup based on a Bruker 125HR high-resolution vacuum Fourier spectrometer, for detection of the luminescence spectra excited by a diode laser, including at cryogenic temperatures (down to

3.5 K) and in magnetic fields up to 500 mT, in the spectral range from infrared to visible, with the resolution up to 0.0006 cm^{-1} (18 MHz). Using this setup, they studied the luminescence spectra of a lithium yttrium fluoride crystal doped with holmium.

Well-resolved hyperfine structure coming from the interaction of optical electrons of the holmium ion with the magnetic moment of its nucleus was detected. Individual hyperfine components are as narrow as 0.002—0.003 cm^{-1}. They split in a magnetic field applied to the crystal, proportionally to their g factors. Several luminescence lines with telecommunication wavelengths (falling into transparency window of optical fibers) and large magnetic g factors (10—15) were found.

Using these lines, the strength of an external magnetic field can be detected with the precision of about 17 μT (compare with the Earth's magnetic field, which ranges from 25 to 65 μT). The direction of the magnetic field can also be determined.

"These luminescence lines are promising for creating remote magnetic-field sensors that do not require an additional constant or variable magnetic field and/or microwave field and are capable of operating in a very wide range of measured magnetic fields. Our results pave the way for the development of a magnetic field sensor for, e.g., quantum repeaters installed in an extended quantum communication line," say the researchers. To implement a practical and convenient sensor, they propose to use an interference filter and a Fabry-Perot interferometer.

Another interesting finding of this research is the possibility to evaluate the lithium isotope ratio in the crystal and random lattice deformations (i.e., the crystal quality) by analyzing high-resolution luminescence spectra.

More information: Kirill N. Boldyrev et al, Observation of the hyperfine structure and anticrossings of hyperfine levels in the luminescence spectra of LiYF4:Ho3+, *Light: Science & Applications* (2022). DOI: 10.1038/s41377-022-00933-2

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