Chip-Scale Atomic Devices: From Atomic Clocks to Brain Imaging and Beyond

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Over the last decade, miniature instruments based on microfabricated alkali vapor cells have emerged as a compelling technology for achieving small size and low-power operation while retaining much of the high precision afforded by the use of atomic spectroscopy. Chip-scale atomic clocks[1] are now a commercial reality[2] and achieve frequency instabilities below 10^{-11} at one hour of integration while consuming only 120 mW of power, 30 times less than any previous commercial atomic clock. This improvement in the power consumption is enabled mainly by the use of a vertical-cavity surface emitting laser as the light source and by the small size and good thermal isolation of the physics package.

Chip-scale atomic magnetometers are also nearing commercial reality and are currently achieving magnetic field sensitivities in the range of 20 fT/√Hz in a low-field environment[3] and below 10 pT/√Hz at earth's field[4]. Our group has been investigating application of chip-scale atomic magnetometers to measurements of magnetic fields produced by the human body and has demonstrated the ability to measure signals from both heart[5] and brain[6].

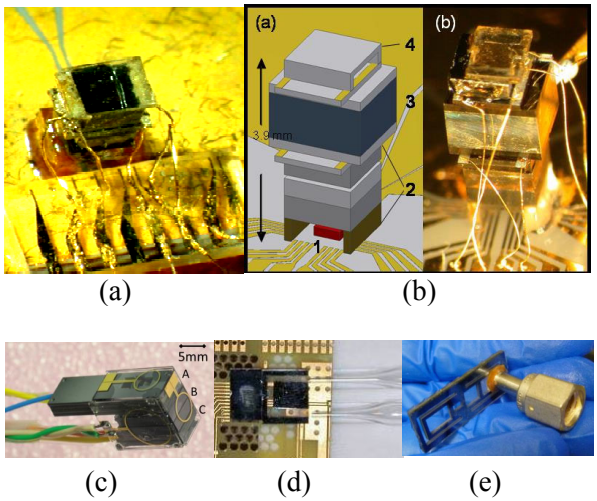

Fig. 1: Chip-scale atomic devices. (a) The first operating chip-scale atomic clock physics package, (b) a chip-scale atomic magnetometer, (c) a fiber-optically coupled chip-scale atomic magnetometer, (d) a microfluidic chip for low-field detection of nuclear magnetism and (e) a chip-scale hyperpolarized Xe source.

We are also investigating the use of chip-scale atomic magnetometers in nuclear magnetic resonance. The high sensitivity of atomic magnetometers at low frequencies enables the remote detection of NMR signals in low magnetic fields where pickup coils are unable to operate well[7]. Finally, we discuss a chip-scale source of hyperpolarized Xe gas that achieves polarization fractions of 0.5 % at flow rates of several microliters per second.

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