Chip-scale Atomic Devices: Miniature Precision Instruments using Atoms, Lasers and MEMS

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We describe recent work at NIST to develop precision instruments based on atomic spectroscopy, advanced semiconductor lasers and micro-electro-mechanical systems (MEMS). These millimeter-scale instruments achieve take their high stability or sensitivity from the use of atoms, but have considerably reduced power consumption and potentially reduced manufacturing cost compared to their larger counterparts. Physics packages for atomic frequency references with fractional frequency stabilities in the range of 10^{-11} over one hour have been demonstrated. Using similar device designs and processing, magnetometers with sensitivities below 10 fT/√Hz have been demonstrated, making them competitive with commercial SQUID-based sensors without the need for cryogenic cooling. The design, fabrication and performance of these instruments will be described, as well as a number of applications to which the devices are well-suited. Finally, we speculate on possible future directions for chip-scale atomic instrumentation with a focus on the use of laser-cooled atomic samples and tools for fundamental metrology.