Atom Interferometry and Nanolithography

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In the past several years, significant progress has been achieved in focussing atoms using standing wave light fields. With this technique, arrays of lines or spots of atoms have been deposited on substrates, having spacing on the order of half the wavelength of the optical fields used to focus the atoms. It is also possible to use atom interferometric techniques to produce atomic density distributions that have a harmonic spatial variation. In this talk, I will discuss methods for producing and probing atomic gratings having periods equal to $\lambda/2n$, where λ is the wavelength of the optical radiation used to scatter the atoms and n is an integer. In this manner, one can create nanostructures having periods on the order of tens to hundreds of nanometers. Such gratings may have potential application as “optical” elements in the scattering of soft x-rays. The techniques needed to produce these gratings are closely related to those used in coherent transient spectroscopy, such as free induction decay and photon echoes. An atomic beam passes through one or more field regions, each field region consisting of either a traveling or standing wave optical field. The fields can act as either intensity or phase gratings for the atoms, producing ground state densities that contain spatial harmonics having period $\lambda/2n$. For example, suppose that atoms pass through a resonant, standing wave field. Owing to the nonlinear dependence of the atomic response on the field amplitude, the field can create a ground state atomic density that contains all spatial harmonics of the standing wave field. These ground state spatial gratings quickly wash out as a result of the transverse velocity distribution of the atomic beam, but they can be refocused if the atoms are allowed to pass through a second standing wave field (echo effect). Moreover, different harmonics are focussed at different locations (echo planes) following the second field, allowing one to maximize the contribution of a given harmonic in a given echo plane. The physical principles underlying these processes will be discussed. A distinction will be made between internal state interferometers and de Broglie wave atom interferometers, both of which can be used to produce the higher order spatial harmonics. Methods for isolating and probing a specific n^{th} order spatial harmonic will be presented. The theory will be compared with the results of recent experiments on magnetic grating free induction decay, magnetic grating echoes, and phase grating (de Broglie wave) echoes.