5/10 Recitation 8.422

A good review on this subject, please see : *Rep. Prog. Phys.*, **76**, 8

1. **Optical Lattice**

Basics - Math

1D case

$$E(x,\ t)\ =\ Sin(kx)\ Sin(\omega t)$$
$$I(x,\ t)\ = Sin^2(kx)\ Sin^2(\omega t)$$

ω here is the frequency of the oscillation of the electric field. It is in the *optical regime ~ 10^15 Hz.* This frequency is much much higher than the typical response time of an atom (usually the frequency). Therefore when discussing the center of mass motion of an atom, we can simply take the time average of *I(x, t)*

$$I(x)\quad =\quad < I(x,\ t)>_t\ = (1/2)Sin^2(kx)$$

Consequently, the AC stark shift has a standing wave pattern which is a lattice.

2D case

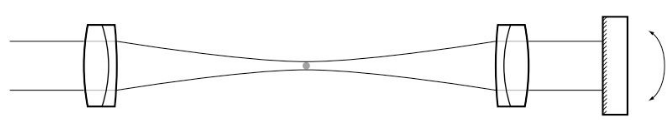
In 2D case, we have the crosstalk between the light in the *x* and in the *y* direction. When taking the time average

$$\begin{aligned}\mathbf{E} &= \vec{E}_1 + \vec{E}_2 \\ &= \vec{\varepsilon}_1 \sin(kx)\sin(\omega_1 t) + \vec{\varepsilon}_2 \sin(ky)\sin(\omega_2 t)\end{aligned}$$

When we are calculating the intensity and taking the time average, the corssterm involves an oscillation at the frequency $\omega_1 - \omega_2$. This oscillation could be comparable to the recoil of an atom therefore cannot be simply ignored.

Experimentally, we usually make $\omega_1 - \omega_2$ larger enough (~10MHz) to make sure the crossterm doesn't affect. In some special cases, the crossterm is kept by setting $\omega_1 - \omega_2 =\ 0$. We then can take advantage of the crossterm to achieve fast switching of the lattice geometry or construct exotic lattice patterns.

Basics - Implementation



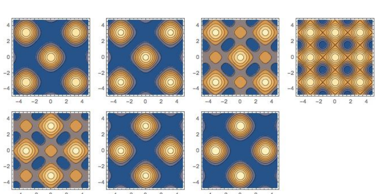
Collimated light -> focusing lens (focusing the beam to get high intensity) -> collimation lens -> retro.

2. **2D-optical lattice**

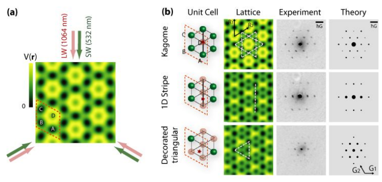
Several examples on the 2D optical lattice

$$V(y,z) = -V_{lat}\left\{\cos^2(ky) + \cos^2(kz) + 2\,\mathbf{e}_1\cdot\mathbf{e}_2\ \cos\phi\ \cos(ky)\cos(kz)\right\}.$$

a. Traditional Lattice

 Different \phi results in different patterns	$V(y,z) = -V_{lat}\left\{\cos^2(ky) + \cos^2(kz) + 2\,\mathbf{e}_1\cdot\mathbf{e}_2\ \cos\phi\ \cos(ky)\cos(kz)\right\}.$ ● Considering the interference between the two lattice arms, the relative phase \phi allows much more possible lattice configurations. ● If \phi is under-control, it is a knob to switch the lattice configuration quickly. ● If \phi is oscillating fast (~10MHz in real experiments), it can be averaged out can gives no actual interference. ● If \phi is random, it will a noise source which we don't want.

b. Kagome Lattice



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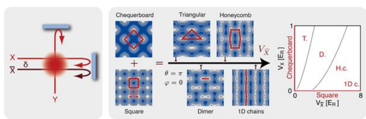
- Geometrically frustrated - the spin frustration we discussed in the recitation.
- Highly-degenerated band - flat band.
- Possible spin liquid as the ground state

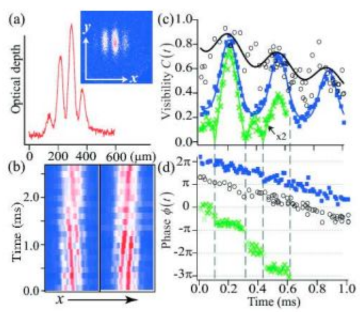
c. Hexagonal Lattice



Nature, **515**, 237

- Realizing the Graphene style hexagonal lattice.
- Dirac points in the system
- Topologically non-trivial without breaking the time-reversal symmetry.

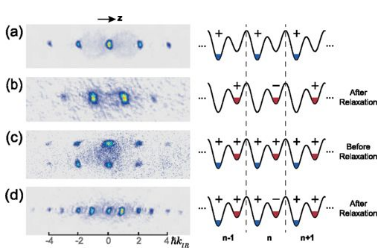
3. 2 - color optical lattice - superlattice

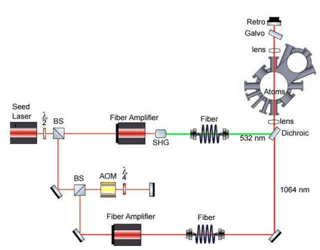


Phys. Rev. Lett. **98***,* 200405

- Interference between the condensates released from two wells.
- Measuring the offset with the periodicity of the oscillation
-

For the Josephson effect we talked about, please see, Oberthaler, Journal of Physics B: Volume 40, Number 10





Phys. Rev. Lett. **117***,* 185301

Nature, **543***,* 91

- Left and Right well as the pseudo-spin degree of freedom
- Tunable Superlattice geometry
- High miscibility due to low small wavefunction overlap