回顾: HE, anormalous HE spin HE.

dopping

Yugui Yao, Qian Niu PRL 2006 $\Delta \sim 10^{-3}$ meV

{ Kane, Mele
{ Bernevig - Hugh - Zhang 2006 → DFT 材料 → 数据库.

HgCdTe / HgTe

2007 实现

↓ 实现

振动

物理学报: 拓扑物理前沿.

水波

量子模拟

声子

电路. LC振荡回路.

表面等离激元. Maxwell eq.

拓扑光子学

磁性: 拓扑磁子

Topo active material

活性物质.

多体

arxiv. 2301.00472

Interacting SSH model

MC

Kondo effect → Topo Kondo effect

AL →

SC →

Ta As.

Fermi arc

project 选题　　分类

物理实现

物理性质的计算.

几何相的计算.

$$\gamma = i\oint \langle\psi|\nabla|\psi\rangle\cdot d\Omega \qquad \int f(x)\,d(x) \Rightarrow \sum_i \delta x_i f(x_i).$$

$$= \sum_{\vec R} i\left\langle\psi(\vec R)\middle|\frac{\psi(\vec R+\delta\vec R)-\psi(\vec R)}{\delta\vec R}\right\rangle d\vec R$$

$$= \sum_{R} i\left[\langle\psi(\vec R)|\underbrace{\psi(\vec R+\delta\vec R)\rangle}_{e^{i\delta Q}} - 1\right]$$

$$x = \ln(1+x) \qquad x\to 0$$

$$\Rightarrow \sum_R i\left[\ln(\langle\psi(\vec R)|\psi(\vec R+\delta\vec R)\rangle) - 1 + 1\right].$$

$$= i\sum_n \ln\langle\psi_n|\psi_{n+1}\rangle.$$

$$= i\ln\prod_n\langle\psi_n|\psi_{n+1}\rangle.$$

$$\overset{e^{i\theta_2}}{\downarrow}\quad \overset{e^{-i\theta_2}}{\downarrow}$$
$$\langle\psi_1|\psi_2\rangle\langle\psi_2|\psi_3\rangle\cdots$$

$\ln z_1 + \ln z_2 = \ln z_1 z_2$　相差 $2n\pi i$.

$e^{i\gamma}$ well defined at $[0, 2\pi)$.

Spin HE 实现 HgCdTe / HgTe.

① strong SOC ⇒ graphene $\Delta \sim 10^{-3}$ meV.

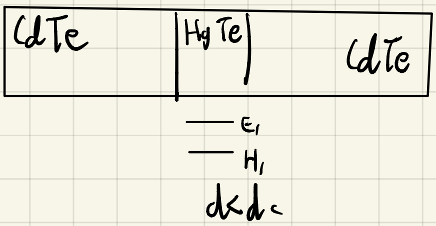
② 小的 Energy gap. 红外光电探测器.

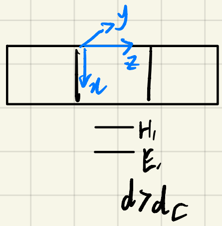
0.2–0.5 eV

1eV ~ 10^4 K

$$H = \begin{pmatrix} h(\vec{k}) & 0 \\ 0 & h^*(\vec{k}) \end{pmatrix}$$ TRS.

HgTe





能带反转.

$k_z^2 \sim \frac{\pi^2}{d^2}$ 驻波.

$$h(\vec{k}) = \begin{pmatrix} \varepsilon_k + M_k & A k_- \\ A k_+ & \varepsilon_k - M_k \end{pmatrix}$$

$\varepsilon_k = C - D k^2$

$M_k = M - B k^2$

$k = (k_x, k_y, k_z)$

$k_- = k_x - i k_y$.

Konig Science 318, 766 (2007).

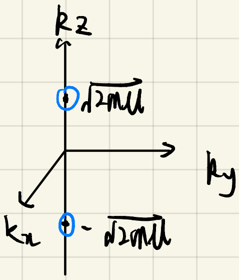
$d_c \sim \mu m$

3d system and Weyl semimetal

$$H=\begin{pmatrix}\varepsilon_k & Ak_- \\ Ak_+ & -\varepsilon_k\end{pmatrix} \qquad \begin{cases}k_- = k_x - ik_y \\ k_+ = k_x + ik_y\end{cases}$$

$$\varepsilon_k = \frac{k_x^2+k_y^2+k_z^2}{2m} - \mu.$$

无能隙 $\begin{cases}k_x = k_y = 0 \\ k_z = \pm\sqrt{2m\mu}\end{cases}$



$$k=\sqrt{2m\mu}+\delta k_z$$

$$k_x^2 = 0 = k_y^2$$

$$\frac{k_z^2}{2m}-\mu = \frac{(\sqrt{2m\mu}+\delta k_z)^2}{2m} - \mu$$

$$= \frac{2\mu}{\sqrt{2m}}\delta k_z$$

$$H_{eff} = \begin{pmatrix}\frac{2\mu}{\sqrt{2m}}\delta k_z & Ak_- \\ Ak_+ & -\frac{2\mu}{\sqrt{2m}}\delta k_z\end{pmatrix}$$

$\vec{B}\cdot\vec{\sigma}$ 零点移动.

1T ~ 0.1 meV

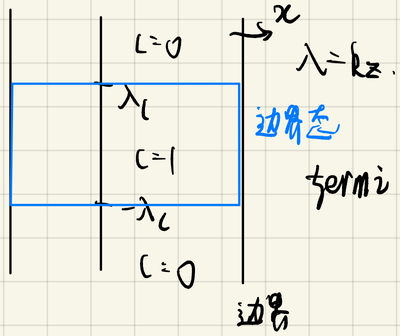
如何描述拓扑因子: $d=3$.

$$H(k_x, k_y, k_z) = H(k_x, k_y, -k_z)$$

k_z $\begin{cases}\text{动量} \\ \text{参数}\end{cases}$ $k_z=\lambda \Rightarrow H_\lambda(k_x, k_y)$. Haldane / Qi-Wu-Zhang.

Chen 数

动量空间



边界态

fermi arc.

多个 Weyl point

不同面/晶向

磁场.

边界态 ⇒ 实空间.

2D gapless model

研究: Transport

光电.

2010~2020年.

下一次课　Qian Niu eq of motion

$$\begin{cases} \dot{x} = \frac{\partial H}{\partial p} \\ \dot{p} = -\frac{\partial H}{\partial x} = -e(\vec{E} + \vec{v}\times\vec{B}) \end{cases}$$

$$\frac{\partial}{\partial t}\frac{\partial L}{\partial \dot{x}} = \frac{\partial L}{\partial x}$$

Berry curvature

ε_k 　 $\dot{\vec{r}} = \frac{\partial \varepsilon}{\partial \vec{k}} - \dot{\vec{k}} \times \vec{\Omega}$

黄昆

$$\dot{\vec{k}} = -e(\vec{E} + \vec{v}\times\vec{B})$$