# Proximity-induced surface superconductivity in Dirac semimetal $Cd_3As_2$

Ce Huang†, Benjamin T. Zhou†, Huiqin Zhang, Bingjia Yang, Ran Liu, Hanwen Wang, Yimin Wan, Ke Huang, Zhiming Liao, Enze Zhang, Shanshan Liu, Qingsong Deng, Yanhui Chen, Xiaodong Han, Jin Zou, Xi Lin, Zheng Han, Yihua Wang, Kam Tuen Law, Faxian Xiu*

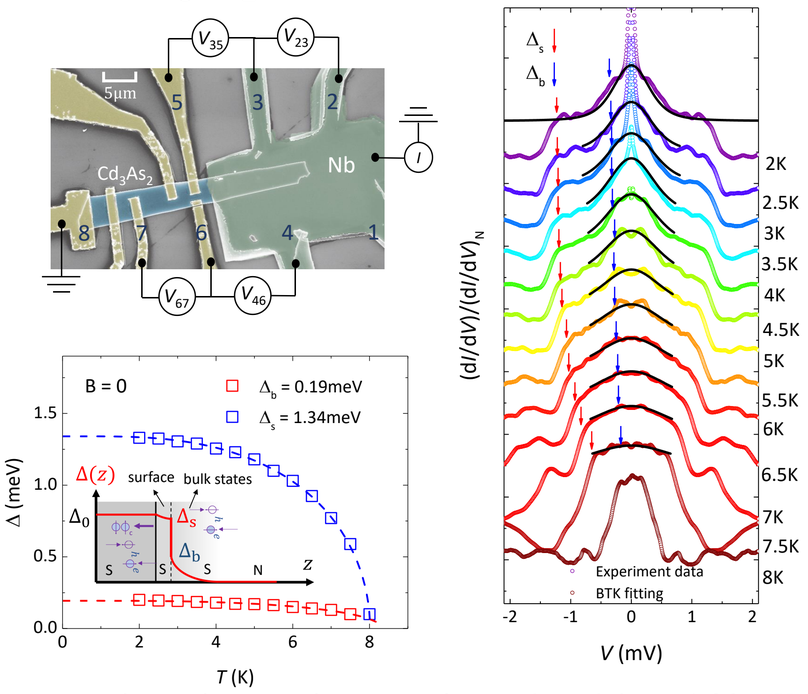
*State Key Laboratory of Surface Physics and Department of Physics, Fudan University, Shanghai 200433, China.*

***Nat. Comm.* 2019, 10, 2217**

## Ⅰ. Abstract

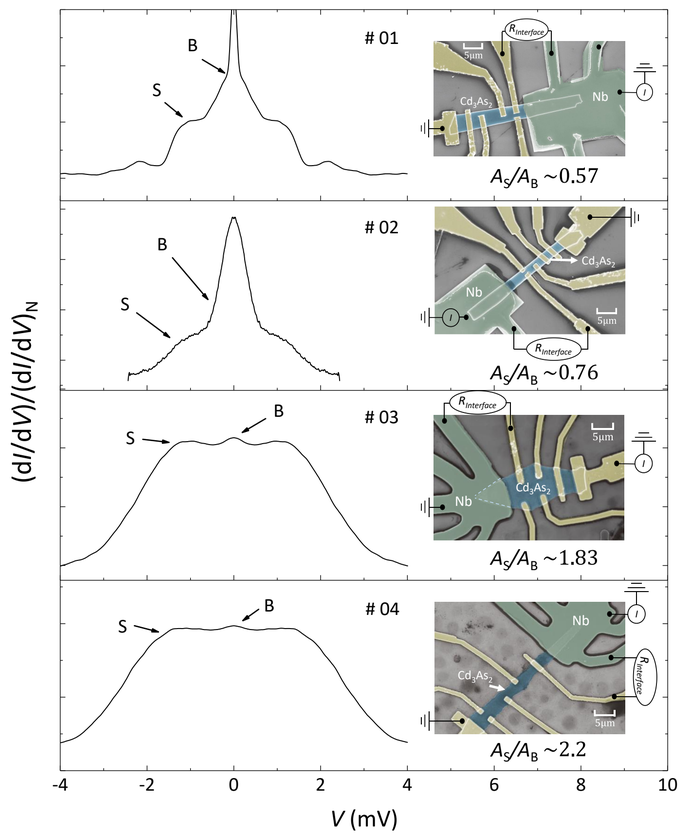
$Cd_3As_2$ is a three-dimensional Dirac semimetal with separated Dirac points in momentum space. In spite of extensive transport and spectroscopic studies on its exotic properties, the evidence of superconductivity in its surface states remains elusive. Here, we report the observation of proximity-induced surface superconductivity in $Nb/Cd_3As_2$ hybrid structures. Our four-terminal transport measurement identifies a pronounced proximity-induced pairing gap (gap size comparable to Nb) on the surfaces, which exhibits a flat conductance plateau in differential conductance spectra, consistent with our theoretical simulations. The surface supercurrent from $Nb/Cd_3As_2/Nb$ junctions is also achieved with a Fraunhofer/SQUID-like pattern under out-of-plane/in-plane magnetic fields, respectively. The resultant mapping shows a predominant distribution on the top and bottom surfaces as the bulk carriers are depleted, which can be regarded as a higher dimensional analog of edge supercurrent in two-dimensional quantum spin Hall insulators. Our study provides the evidence of surface superconductivity in Dirac semimetals.

## Ⅱ. Proximity-induced superconductivity in $Nb/Cd_3As_2$



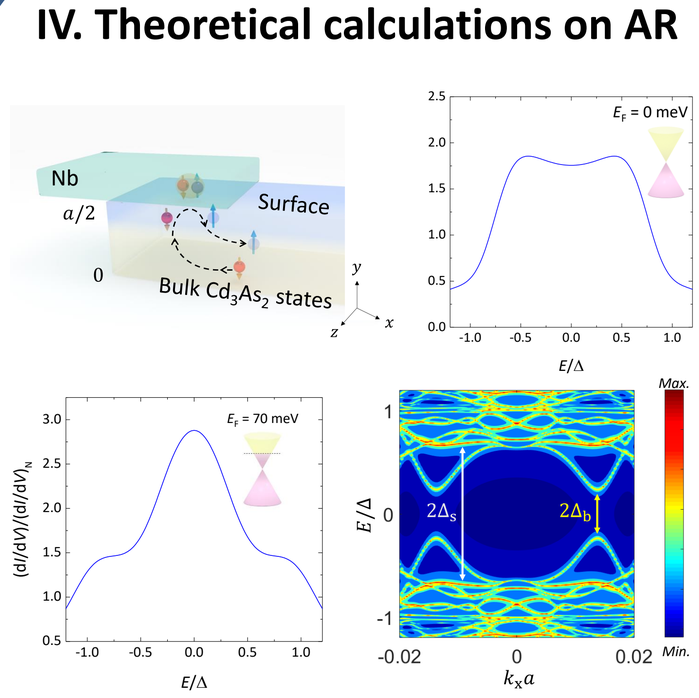

- Bias-independent conductance plateau (BICP) $\Delta_s = 1.20$ mV
- Zero-bias broad peak $\Delta_b = 0.19$ mV, well fitted by BTK theory,
- Both two features show consistent temperature dependence by BCS theory, verifying the proximity effect and s-wave pairing in $Cd_3As_2$

## Ⅲ. Thickness-dependent d*I*/d*V*



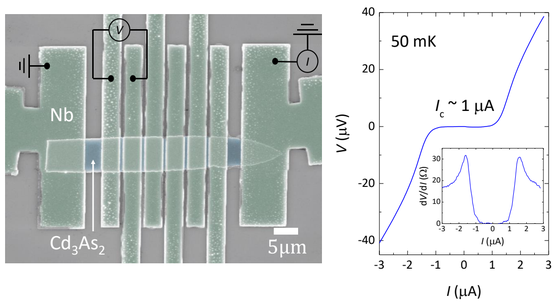

- Device 01-02, ~200 nm, both $\Delta_s$ and $\Delta_b$
- Device 03-04, <150 nm, only $\Delta_s$, indicating surface superconducting gap $\Delta_s$

## IV. Theoretical calculations on AR




- $E_F = 0$ meV: Fermi arc dominated AR, only BICP occurs with $\Delta_s \sim \Delta_{Nb}$
- $E_F = 70$ meV: Both Fermi arc and bulk states dominated AR, BICP and ZBBP exist.
- Evidently, two pairing gaps are induced on the surface. The larger proximity gap $\Delta_s$ originates from Fermi-arc states (with high local density on the surface).

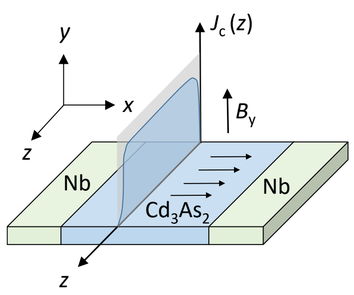
## V. Surface supercurrent in $Cd_3As_2$ Josephson junction

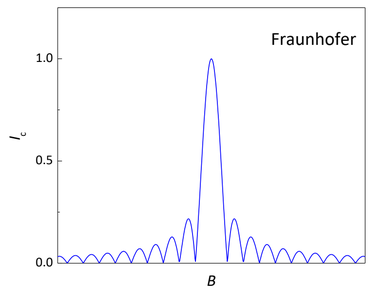


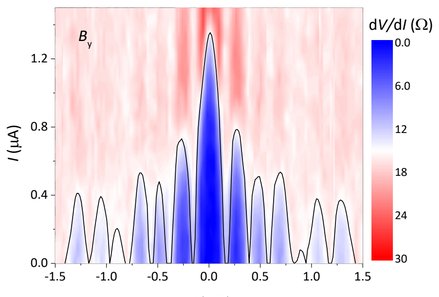


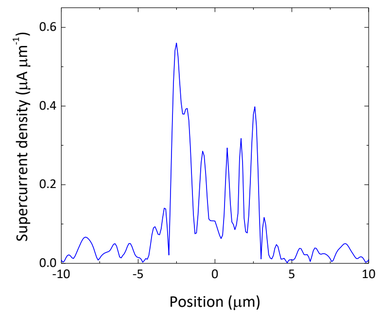


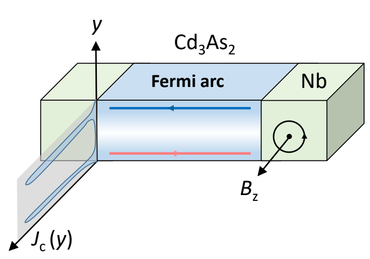
- $L = 500$ nm, $W = 7$ μm, $I_c \sim 1$ μA
- $B \parallel y$, Fraunhofer pattern, universal supercurrent density along z-axis
- $B \parallel z$, SQUID pattern, edge supercurrent along y-axis, which indicates surface supercurrent
- Surface-full regime depths $z_s = 13 - 14$ nm, consistent with Fermi arc region

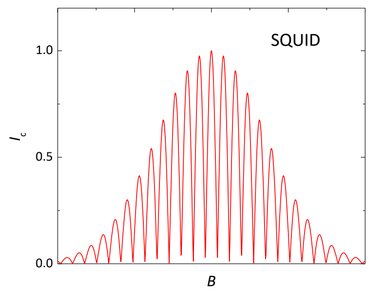


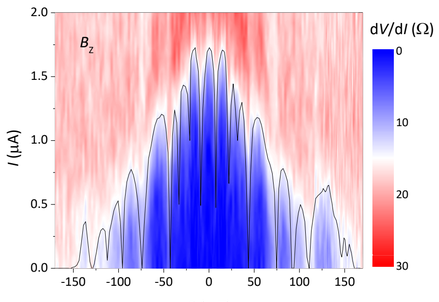



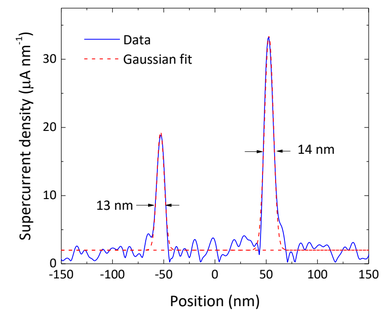



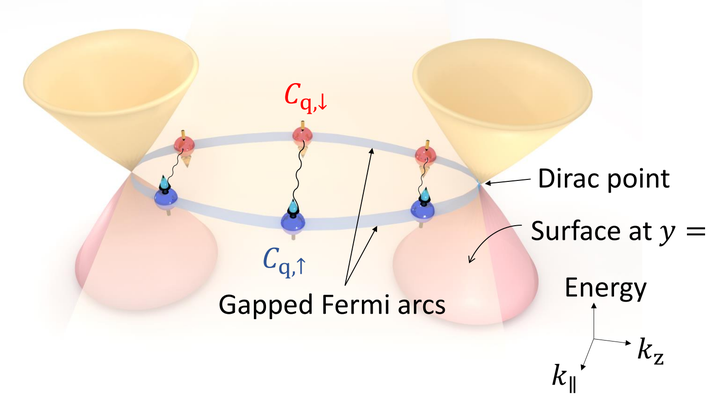



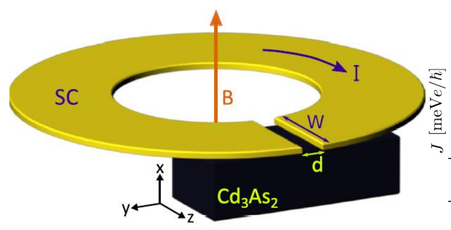



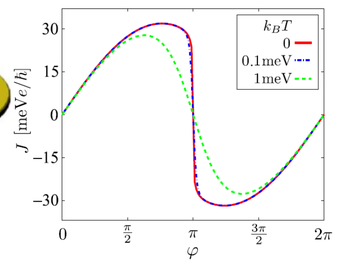




## VI. Prospectives




- Fermi arc superconductivity: Majorana flat bands
- CPR experiments: The Josephson current has a large jump at phase difference $\phi = \pi$

*To whom correspondence should be addressed: faxian@fudan.edu.cn