Modeling and Designing the Electrical Contact of Sliding Interfaces

Song Aisheng[a], Shi Ruoyu[a], Ma Tianbao[a]*
*mtb@mail.tsinghua.edu.cn
[a] State Key Laboratory of Tribology in Advacend Equipment, Tsinghua University, Beijing , People's Republic of China

KEYWORDS
Friction; NanoTribology; Physics of friction, Electrical contact

ABSTRACT

Sliding electrical contacts refer to the interface that transfers current between the moving and stationary parts in a mechatronic system. To achieve low friction wear and low contact resistance of sliding electrical contact, we investigate the basic scientific problems from the perspectives of friction and electrical transmission: (1) In terms of friction, we investigate the regulation effect and mechanism of current on friction; (2) In terms of electrical transmission, we investigate the electrical transmission mechanism and contact conductance regulation methods of van der Waals interface. Based on the theoretical research, we propose a superlubricating electrical contact based on two-dimensional material heterojunctions. The details are as follows:

First, we investigate a unique friction tuning effect induced by an electric current in a conductive atomic force microscopy experiment and uncover two main tuning mechanisms of friction by the fluctuation of electronic properties during sliding: (1) electric-field-induced electron density redistribution and (2) current-induced electron transfer. We put forward an electronic level friction model unraveling the relationship between the friction tuning and the electronic property fluctuation (EPF) under electric field/current, which is applicable to tribosystems ranging from conductors to semiconductors and insulators, including two-dimensional material interfaces [1].

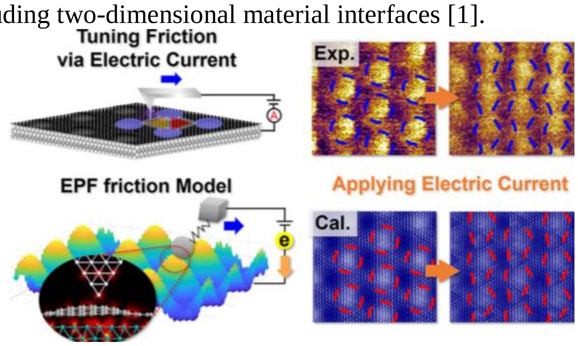

Figure 1. The friction model based on electronic property fluctuation (EPF).

Second, we measure the atomic-scale local electrical contact conductance instead of local electronic surface states in graphene/Ru(0001) superstructure, via atomically resolved conductive atomic force microscopy. By defining the "quality" of individual atom–atom contact (ACQ) as the carrier tunneling probability along the interatomic electron transport pathways, we establish a relationship between the atomic-scale contact quality and local interfacial atomistic structure. This real-space model unravels the atomic-level spatial modulation of contact conductance, and the twist angle-dependent interlayer conductance between misoriented graphene layers [2-4].

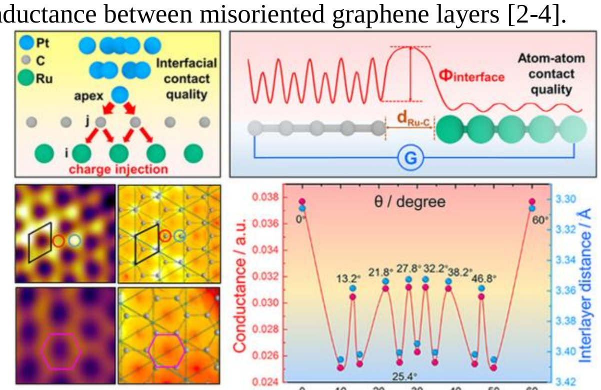

Figure 2. The electrical contact model based on atomic-scale contact quality (ACQ).

Finally, according to the ACQ model and EPF model, we propose the Ti-$MoS_{1.5}$-Gr-Ti superlubricating electrical contact. The first-principles transport calculation shows that the conductivity of this electrical contact is increased by about 78% compared with the traditional Cu-MoS_2-MoS_2-Cu contact, and the sliding barrier is reduced by more than one order of magnitude, which provides a way for engineering to achieve low friction and low resistance sliding electrical contact [5].

REFERENCES

[1] Song, A., Shi, R., et. al. (2022). Fluctuation of interfacial electronic properties induces friction tuning under an electric field. *Nano Letters*, *22*(5), 1889-1896.
[2] Song, A., Shi, R., et. al. (2019). Modeling atomic-scale electrical contact quality across two-dimensional interfaces. *Nano Letters*, *19*(6), 3654-3662.
[3] Zhang, S.*, Song, A.*, et. al. (2020). Abnormal conductivity in low-angle twisted bilayer graphene. *Science advances*, *6*(47), eabc5555.
[4] Zhang, S.*, Xu, Q.*, Hou, Y.*, Song, A.*, et. al. (2022). Domino-like stacking order switching in twisted monolayer–multilayer graphene. *Nature Materials*, *21*(6), 621-626.
[5] Song, A., Gao, L., et. al., (2020). Achieving a superlubricating ohmic sliding electrical contact via a 2D heterointerface: a computational investigation. *Nanoscale*, *12*(14), 7857-7863