西安交通大学
XI'AN JIAOTONG UNIVERSITY

High Output Power Density of a Shear-mode Piezoelectric Energy Harvester based on $Pb(In_{1/2}Nb_{1/2})O_3$-$Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ Single Crystals

Xiangyu Gao*, Zhuo Xu, Fei Li*

Electronic Materials Research Laboratory, Key Laboratory of the Ministry of Education & International Center for Dielectric Research, School of Electronic Science and Engineering, Xi'an Jiaotong University, Xi'an 710049, China

Email: gaoxiangyu@xjtu.edu.cn (X. Gao), ful5@xjtu.edu.cn (F. Li)

INTRODUCTION

Wireless sensing is wildly adopted in Internet of Things (IoT) systems, but the battery replacement is a critical issue for these devices. Piezoelectric energy harvester that can obtain energies from ambient vibrations is thought to be a promising approach to resolve this issue. However, state-of-the-art energy harvesters made from piezoelectric ceramics cannot meet the requirements of most wireless sensors due to the limited power density. Here, we proposed a bridge-type shear-mode piezoelectric energy harvester (BSPEH) based on $Pb(In_{1/2}Nb_{1/2})O_3$-$Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PIN-PMN-PT) single crystals. Owing to the giant figure-of-merit $d_{15}\times g_{15}$ of the crystal and the higher electromechanical transfer efficiency of the flex-tensional structure when compared to cantilever structure, the newly designed shear mode energy harvester showed the power density up to 13.78 mW cm^{-3}, being much higher than that of conventional cantilever energy harvesters based on piezoelectric ceramics (~0.1 mW cm^{-3}). A practical application of wireless sensing and data transmitting system is successfully powered by the newly designed energy harvester. This work may shed a light for addressing the issue on sustainable energy supply of IoT systems.

STRUCTURE AND DESIGN

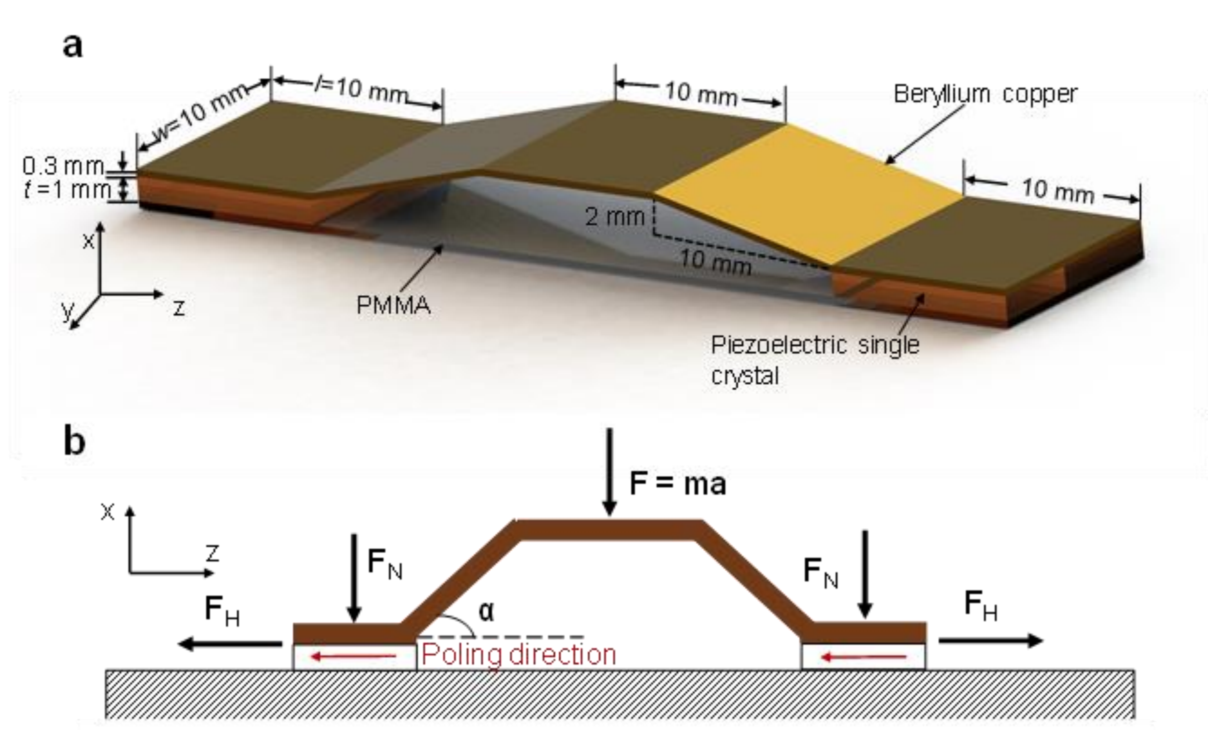

Fig. 1 Working principle of the BSPEH. (a) Schematic of the energy harvester; (b) Mechanical analysis of the structure.

MECHANICAL ANALYSIS

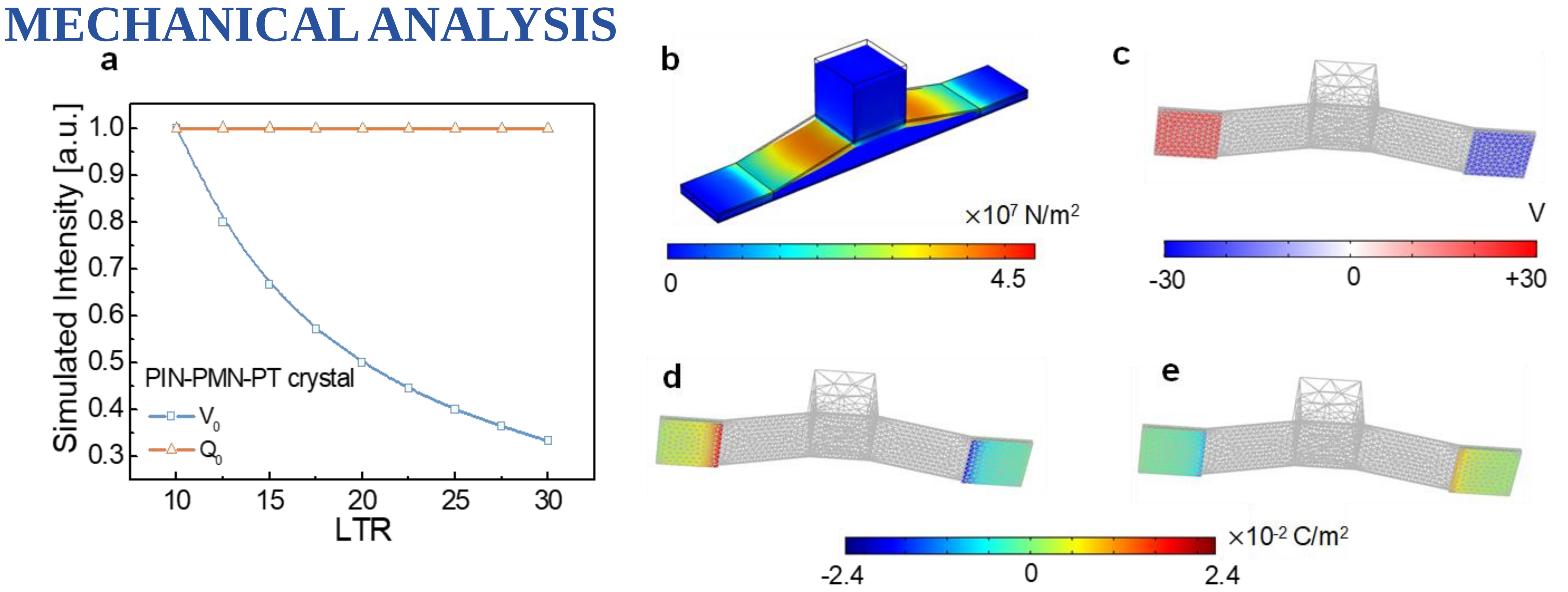

Fig. 2 Output voltage and charge density of BSPEH by FEM simulation. (a) Open circuit output voltage (V_0) and short circuit charge density (Q_0) with different length to thickness ratio (LTR). (b) Stress distribution and (c) output voltage at resonance frequency; and output charge density in short circuit for (d) PIN-PMN-PT crystal and (e) soft piezoelectric ceramic.

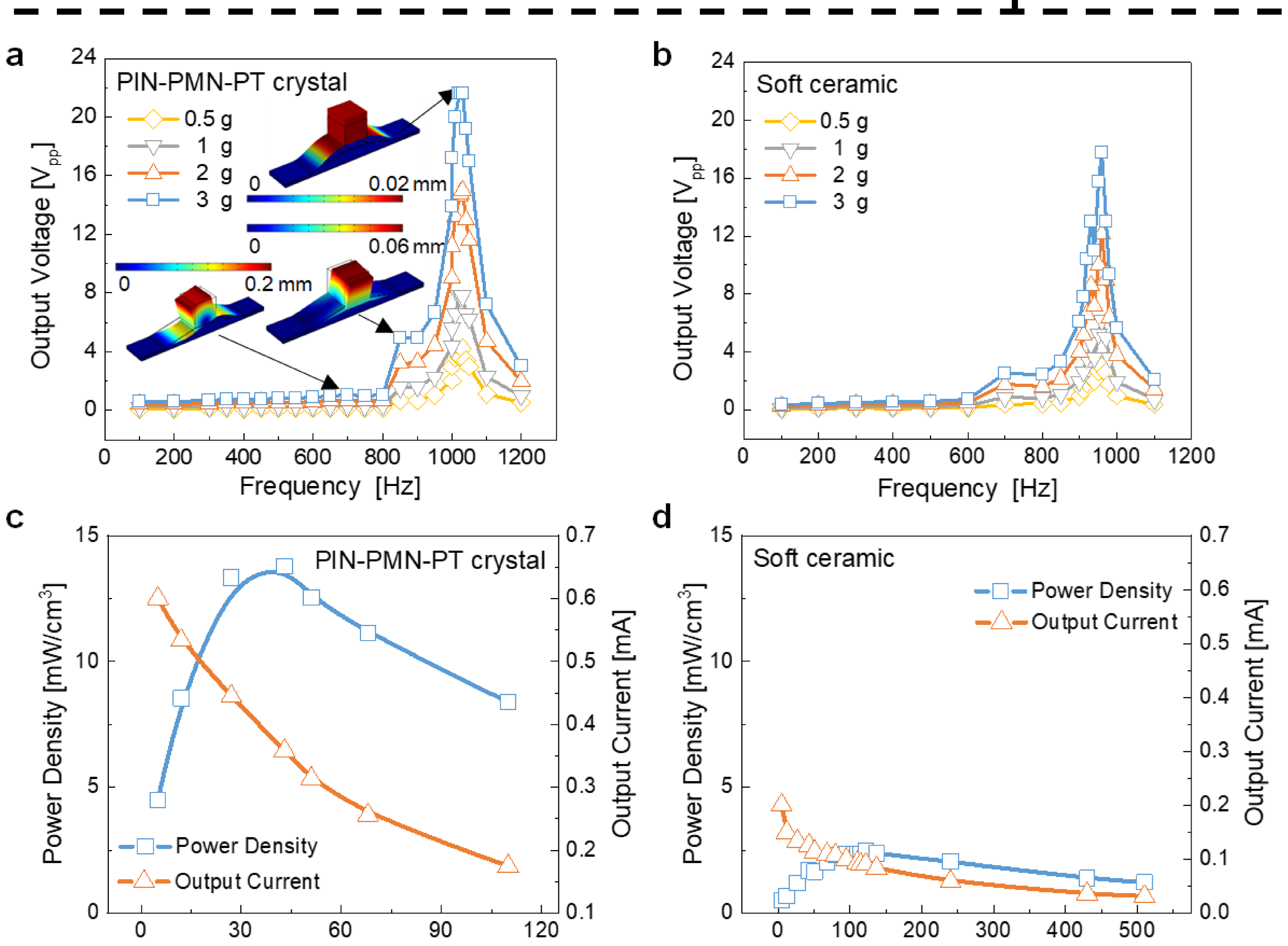

Fig. 3 Energy harvesting performance of BSPEH. (a)(b) Output voltage; (c)(d) output power density and current.

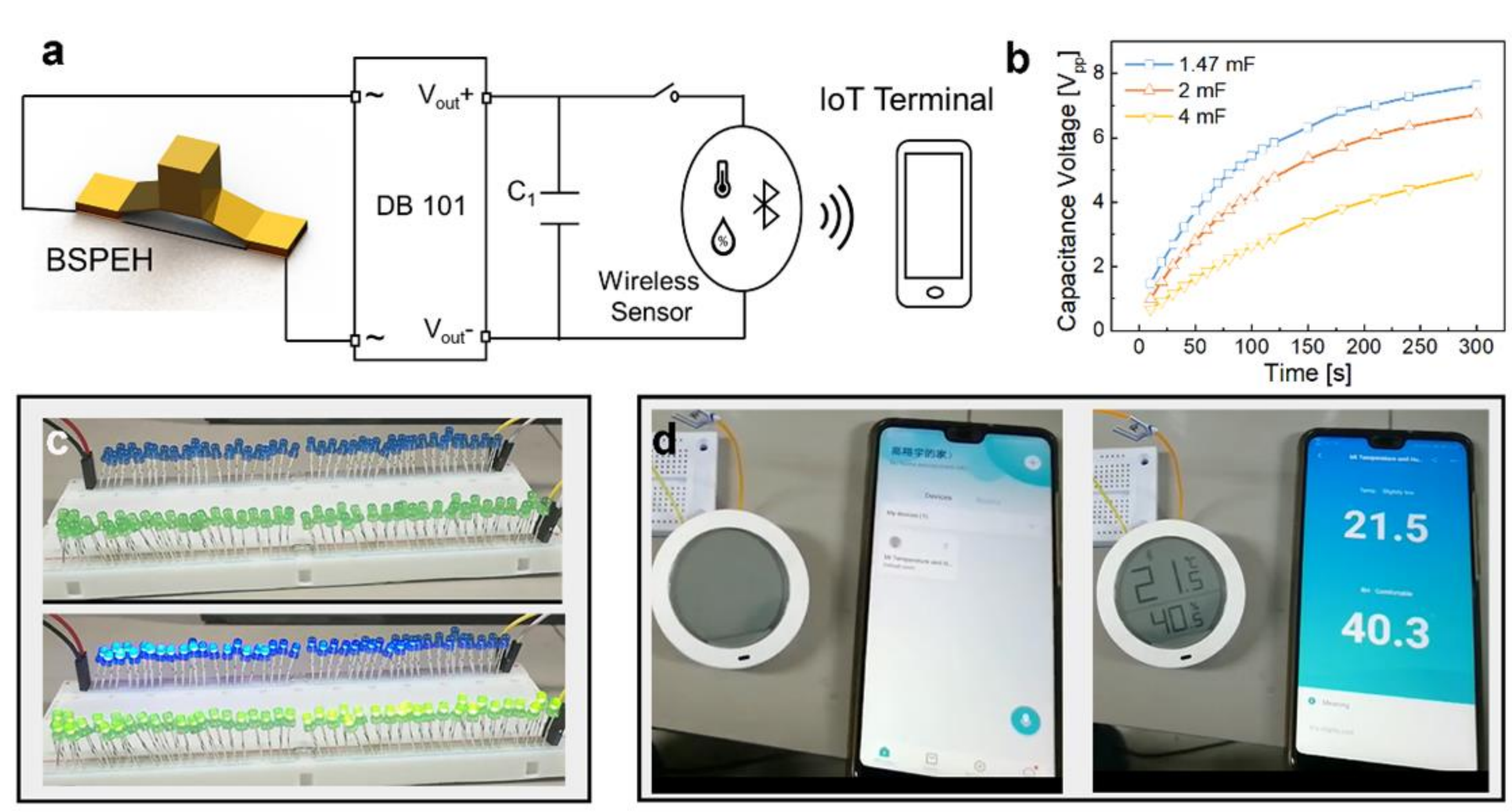

Fig. 4 Practical applications. (a) Circuit diagram for powering wireless sensors in IoT system. (b) Charging behaviour for different capacitance. (c) 200 LEDs are lit up. (d) Wireless sensing powered by the BSPEH.

CONCLUSION

In summary, we designed a BSPEH structure energy harvester by using high-performance PIN-PMN-PT piezoelectric crystals. Owing to the high FOM $d_{15}\times g_{15}$ of PIN-PMN-PT crystals and a bridge-type shear-mode design, a maximum power density of 13.78 mW cm^{-3} was achieved in the newly designed energy harvester, which is 5.5 times higher than that of the same structure energy harvester made by PZT ceramics and superior to state-of-the-art piezoelectric harvesters. The newly designed energy harvester can light 200 parallel connected LEDs at the same time. Furthermore, to demonstrate the feasibility of the harvester in IoT applications, we powered a wireless humidity and temperature sensor by using the newly designed energy harvester.

ACKNOWLEDGEMENTS

This work was supported by the China Postdoctoral Science Foundation (Grant No. 2019M663720) and the Fundamental Research Funds for the Central Universities (Grant No. xxj022019034).