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In-process cutting temperature measurement for ultra-precision machining: a comprehensive review and future perspectives

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Historical overview of Cutting temperature measurement methods

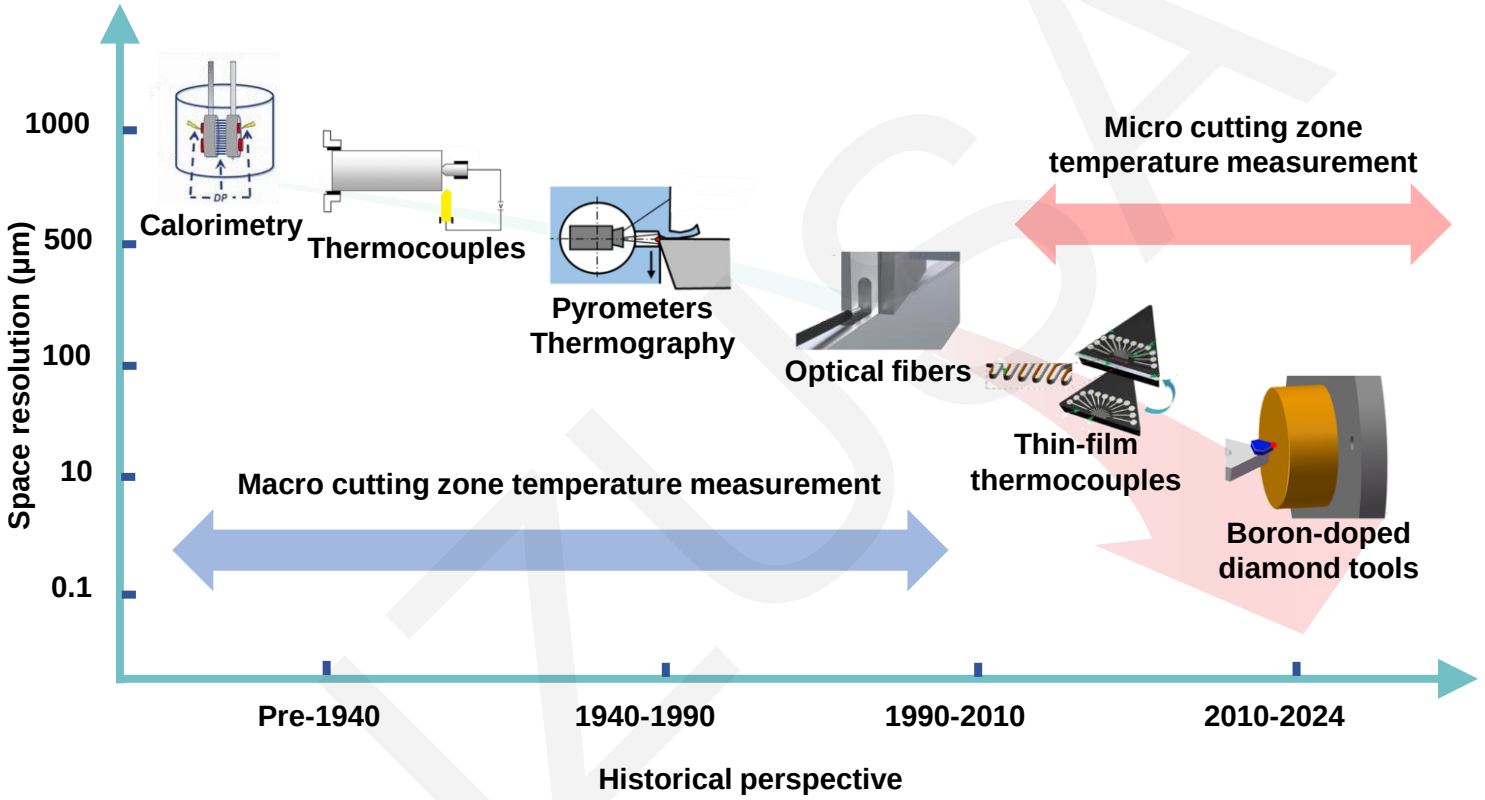


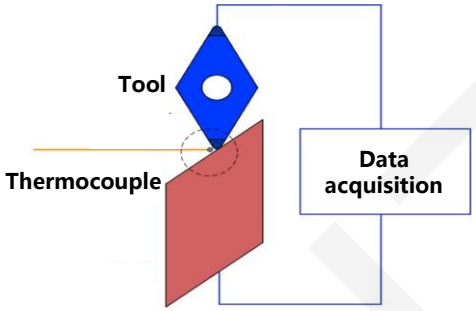
Fig. 1 Historical overview of cutting temperature measurement methods for machining processes

With the progression of machining dimensions into the micro and nanoscale regime, an increasing number of principles and techniques for cutting temperature measurement have been proposed.

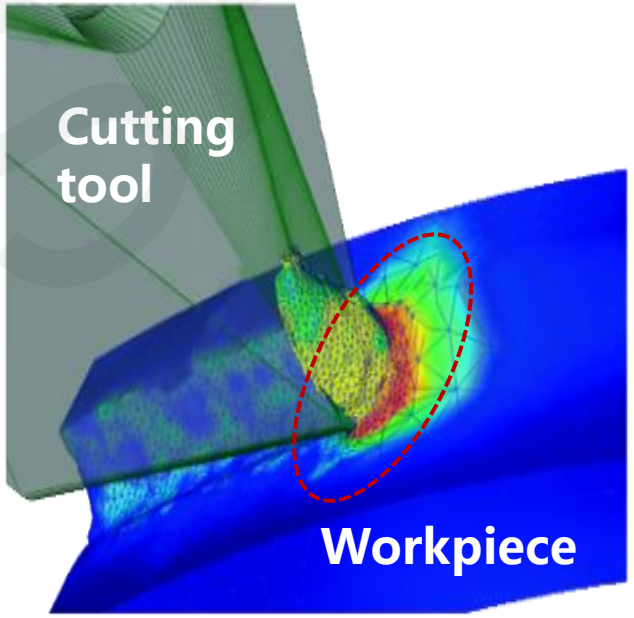
Micro-zone temperature during ultra-precision machining can’t be measured

Infrared thermography

Thermocouple



Additional sensors



Micro/nano scale cutting zone

Due to limitations in spatial accessibility, traditional additional sensors are unable to directly measure the micro-zone cutting temperature during ultra-precision machining processes.

Solution 1
Micro-scale sensor-integrated tools

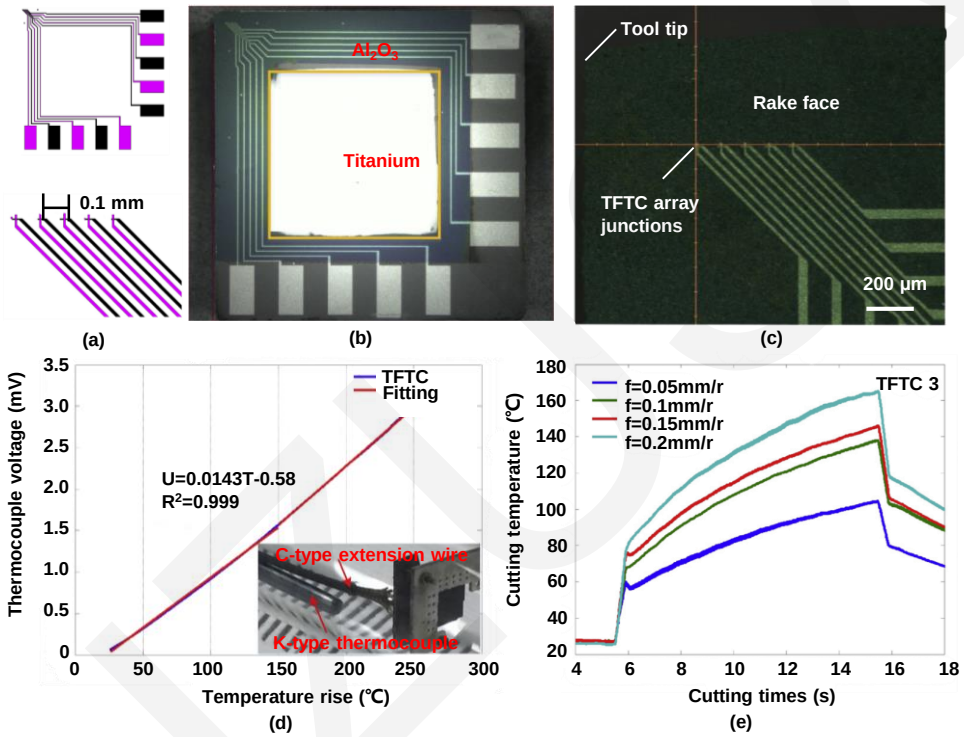


Fig. 16 Micro-zone cutting temperature measured by thin-film thermocouple array

The shift towards micro sensor-integrated cutting tools addresses spatial resolution limitations through direct integration within cutting edge, with micrometer scale positional accuracy.

Solution 2
Self-sensing of temperature cutting tools

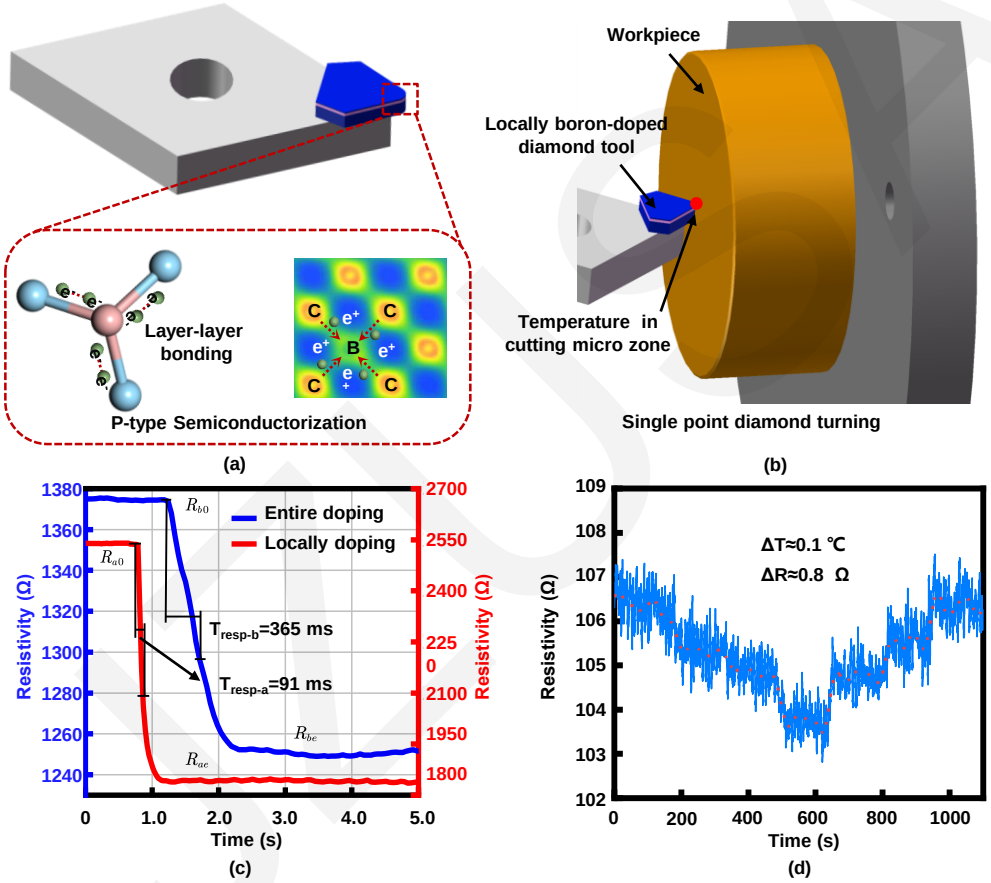


Fig. 20 Micro-zone cutting temperature directly measured by self-sensing diamond tool

Recent advancements of micro-zone cutting temperature monitoring technologies through innovation of tool materials, integrating heat sensing capabilities into tools themselves.

Future perspectives 1
Cutting temperature monitoring in ACSM

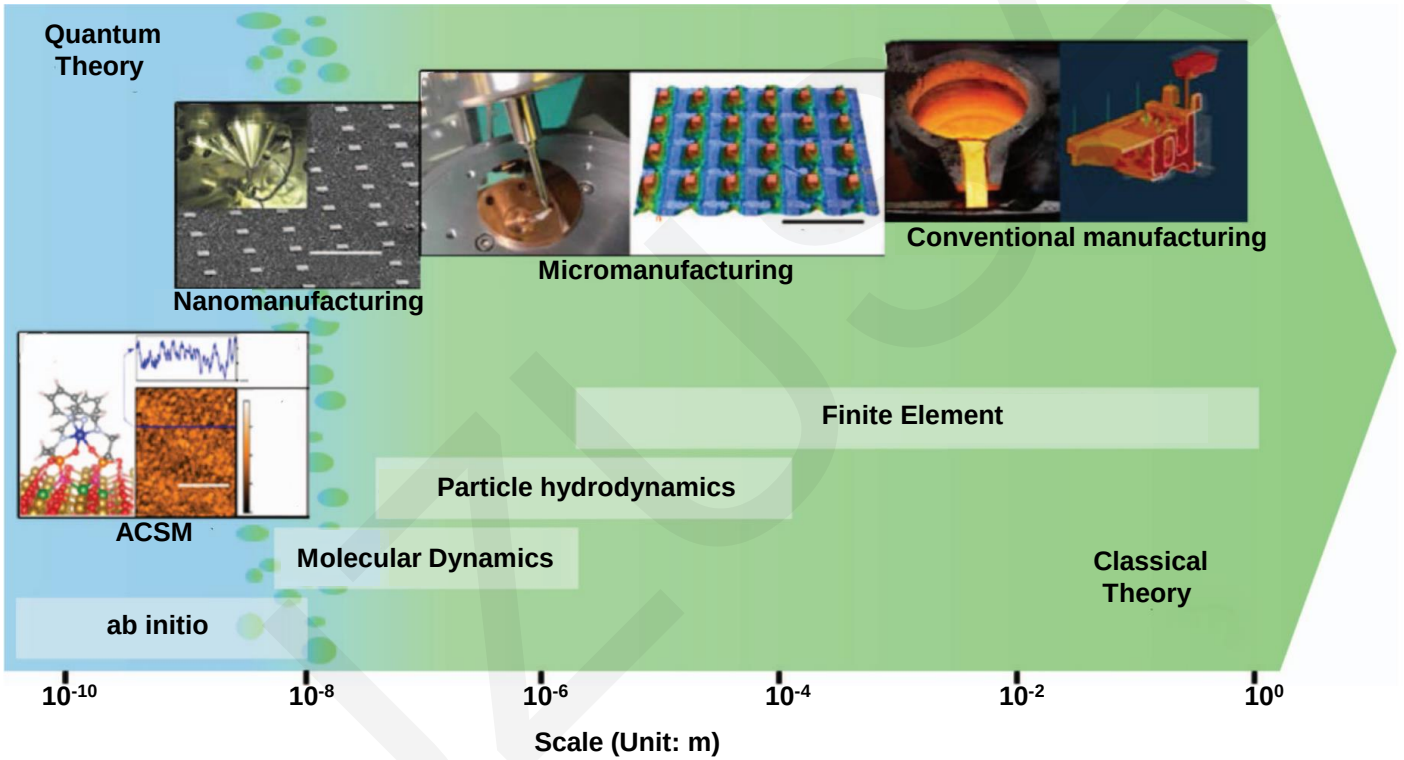


Fig. 21 Length scale map of manufacturing systems, modeling methods, and dominant theories

Progressive miniaturization of equipment and processes, heading towards atomic-scale manufacturing, will likely necessitate temperature measurement methods with atomic-level spatial resolution and microkelvin thermal sensitivity.

Future perspectives 2
AI-driven smart temperature sensor networks, multimodal data fusion and IoT

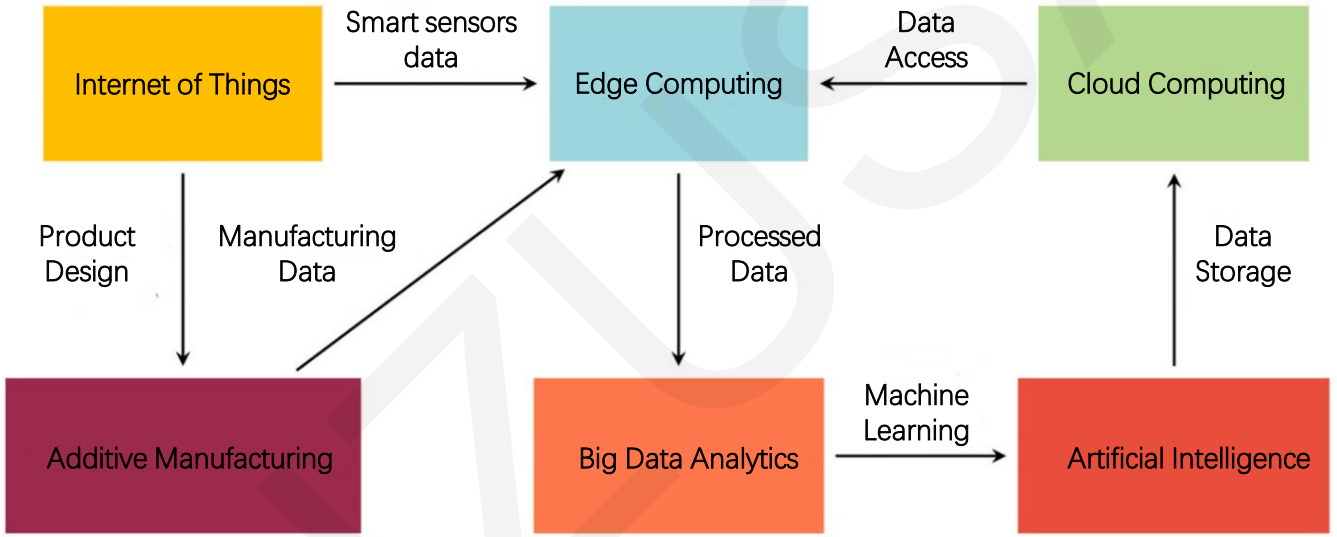


Fig. 21 Different components of intelligent manufacturing in Industry 4.0

The convergence of AI-driven adaptive sensing systems and internet of things (IoT)-enabled distributed measurement networks will enable real-time monitoring, prediction, and control of machining temperature.

Conclusions

- Traditional temperature measurement methods face challenges in terms of meeting the temperature measurement with micro/nano-scale cutting zones.
- With the continuous development of miniaturized and integrated sensors, new cutting temperature measurement methods are being rapidly developed.
- The development of smart sensors and IoT technology has enabled real-time data collection and remote monitoring, significantly advancing temperature control capabilities in UPM and ACSM.