

# 23 Nanotribology of MEMS/NEMS

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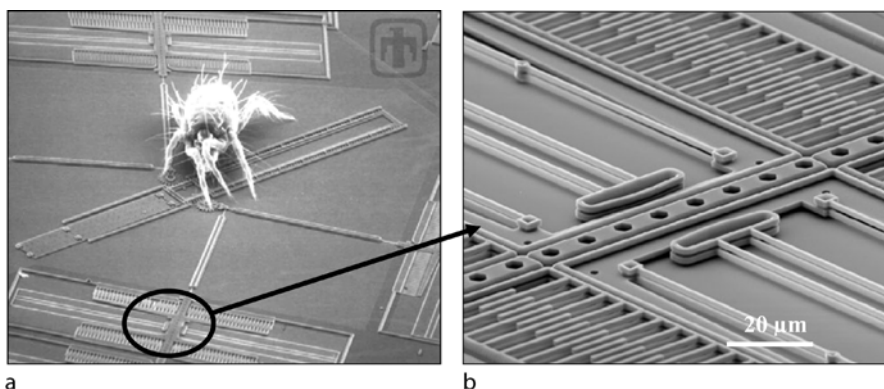
## List of symbols

Symbol	Definition	Units
$r$	Radius of a meniscus	m
$R$	Radius of a ball	m
$\gamma_l$	Surface tension of a fluid	J/m <sup>2</sup>
$F_{\text{cap}}$	Capillary force between ball and counterbody	N
$z$	Distance of separation between two surfaces	m
$d_{\text{cap}}$	Characteristic distance for capillary condensation	m
$\theta$	Contact angle	–
$e_{\text{cap}}(z)$	Interaction energy function	J/m <sup>2</sup>
$A_{\text{Ham}}$	Hamaker constant	J
$d_{\text{ret}}$	Maximum distance between molecules for Van der Waals forces	m
$d_{\text{co}}$	Cutoff distance between molecules for repulsive interactions	m
$e_{\text{vdW}}$	van der Waals interaction function	J/m <sup>2</sup>
$F_{\text{total}}$	Total normal force	N
$F_{\text{applied}}$	External applied normal force	N
$F_{\text{adhesion}}$	Adhesion force	N
$F_a$	Pull-off force	N
$\gamma$	Work of adhesion	J/m <sup>2</sup>
$\Gamma$	Surface-interaction energy	J/m <sup>2</sup>
$t$	Thickness of beam	m
$h$	Initial separation between substrate and cantilever	m
$s$	Deflection length of a cantilever	m
$F_f$	Friction force	N
$a$	Modified Hertzian contact length	m
$\mu$	Coefficient of friction	–
$L$	Applied normal force	N
$K$	Effective elastic modulus of a material couple	N/m <sup>2</sup>

### 23.1 MEMS/NEMS Devices, Applications, and Their Reliability Issues

The miniaturization of devices continues to fuel the integrated circuit industry. The fabrication of micro-/nanosized complex structures and devices have been made possible thanks to the advancement in lithographic techniques. Micro-/nanoelectromechanical systems (MEMS/NEMS) form an integral part of the microelectronic industry. In 2000, the MEMS/NEMS industry was worth approximately \$15 billion and with a projected 10–20% annual growth rate, it is expected to be worth more than \$100 billion by the end of this decade [1]. MEMS/NEMS devices are a group of products ranging in size from a micrometer to a centimeter that combine mechanical and electrical structures. They may also consist of micromechanical components such as comb drives, microgears, microlevers, etc., which move to perform certain tasks, and microelectronic components to control motion or to obtain information from that motion [2]. To give an idea of their size and complex structure, a spider mite next to a MEMS device with a series of comb drives is shown in Fig. 23.1 [3]. MEMS technology is a general term used for materials and processes required to make MEMS components, the integration of such components to make devices (e.g., sensors, actuators), and their applications. MEMS/NEMS find a wide range of applications in engineering fields ranging from electronic devices, space technology to biological sciences due to their existence in many forms and the ability to engineer these devices as necessary for given applications [4]. MEMS are commercially used in inkjet printer heads, microwave switches, accelerometers, and sensors.

The future of MEMS/NEMS looks bright as new types of microsystems emerge in drug-delivery systems, optical switches, chemical lab-on-a-chip systems, gas-turbine engines, microgears, chemical sensors, infrared im-



**Fig. 23.1.** MEMS device along with a spider mite indicating the size of these microcomponents, **b** zoom-in of the picture showing comb drives (series of aligned cantilevers) used in MEMS devices [3]