This chapter comprises some applications which combine two or more force measurement principles, as well as force transducers based on sensors difficult to include in a certain category, like carbon nanotubes (CNTs).

With small dimensions and a combination of excellent mechanical and electrical properties, CNTs could find their way into nanoelectromechanical systems [16.1]. They have a Young’s modulus of 1 TPa, i.e. five times larger than the best steel and also five times larger than high-quality carbon fibers, being considered to be the “ultimate” devices in this field. Their electronics applications spectrum includes field effect transistors and FET arrays, CMOS-integrated chemical- and bio-sensors, interconnected circuits for VLSI chips (vias). Two examples of mechanical quantities measurement are presented in Figure 16.1, with proper explanations given in Chapter 16.3.

**Fig. 16.1** a) A practical device for surface profiling, based on the nano-oscillator concept in the GHz range, where an inner tube from a finite length double wall CNT oscillates inside an open ended outer nanotube acting as a shutter for the laser beam path to the detector. b) Two CNTs grown out from catalytic metal dots on electrodes and attached to each other by van der Waals forces to form a bimorph sensor/actuator.
16.1. FORCE TRANSDUCERS USING ADVANCED ELECTRONICS

Solid-state piezoresistive potentiometers have replaced the classical ones (with wiper sliding on resistive wires or films), utilized in the field of mechanical quantities measurement [16.2]. Furthermore, their steady evolution has gone to silver-complexes as reversible electron transfer agents between the organic polymer film and the underlying solid-state conductor, resulting in highly reproducible starting EMF (electromotive force) values and improved initial signal stability [16.3]. Polymeric membranes (usually in force and/or pressure measurements) doped with appropriate lipophilic ion-exchangers can be also used to conveniently detect low levels of polyion species by simple potentiometry, based on a classical ion-selective electrode (ISE) configuration.

A transducer consisting of multiple layers of ionic polymer material is developed for applications in sensing, actuation and control [16.4]. A multilayer transducer is fabricated by layering individual transducers on top of one another. Each multilayer transducer consists of two to four individual layers of approx. 200 µm thickness. The electrical characteristics of the transducers can be varied by connecting the layers in either a parallel arrangement or a series one. The tradeoff in deflection and force is obtained by controlling the mechanical constraint at the interface. Packaging the transducer in an outer coating produces a hard constraint between layers and reduces the deflection with a force that increases linearly with the number of layers. This configuration also increases the bandwidth of the transducer. Removing the outer packaging produces an actuator that maintains the deflection of a single layer with an increased force output. This is obtained by allowing the layers to slide relative to one another during bending.

A model based on a linearly coupled, two ports, electrical equivalent circuit, to allow the design and evaluation of encapsulated ionic polymer transducers, is developed in [16.5]. Modal expansion is used to extend the applicability of the mechanical impedance terms through multiple resonances of the transducer. Charge sensing and blocked force (the maximum force an actuator can generate if blocked by an infinitely rigid restraint) were found to increase for a transducer after encapsulation, due to the higher coherence.

Solid-state actuators based on piezoelectric and magnetostrictive materials are characterized by forces reaching the range of kilonewton and reaction times in the range of microseconds [16.6]. Their multi-valued statical characteristics can be solved by driving in a closed loop control. The actual values, e.g. forces or displacements, are measured and fed to a controller, which generates suitable corrective signals in accordance with the intended values.

A force transducer with a silicon vacuum microcavity [16.7] has a cold field-emission cathode and a movable diaphragm anode (Fig. 16.2).