Electrical nanogap devices for biosensing

For detecting substances that are invisible to the human eye or nose, and particularly those biomolecules, the devices must have very small feature sizes, be compact and provide a sufficient level of sensitivity, often to a small number of biomolecules that are just a few nanometres in size. Electrical nanogap devices for biosensing have emerged as a powerful technique for detecting very small quantities of biomolecules. The most charming feature of the devices is to directly transduce events of biomolecules specific binding into useful electrical signals such as resistance/impedance, capacitance/dielectric, or field-effect. Nanogap devices in electrical biosensing have become a busy area of research which is continually expanding. A wealth of research is available discussing planar and vertical nanogap devices for biosensing. Planar nanogap devices including label-free, gold nanoparticle-labeled, nanoparticles-enhanced, nanogapped gold particle film, and carbon nanotube nanogap devices as well as vertical nanogap devices with two and three terminals for biosensing are carefully reviewed. The aim of this paper is to provide an updated overview of the work in this field. In each part, we discuss the principles of operation of electrical biosensing and consider major strategies for enhancing their performance and/or key challenges and opportunities in current stages, and in their further development.

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Electrical biosensors rely solely on the measurement of currents and/or voltages to detect binding[1,2]. Owing to its inherent superiorities of electrical transduction methods, such as excellent compatibility with advanced semiconductor technology, miniaturization, and low cost, biosensors based on electrical detection are capable of behaving at high performance with a simple miniaturized readout[3,4]. Nanogap electrodes are defined as a pair of electrodes with a nanometer gap[5]. Nano sized biomolecules can be trapped into a gap between two electrodes and connecting the electrodes; the biomolecules are therefore detected by observing their electrical behavior (resistance/ impedance, capacitance/dielectric, or field-effect)[6].

By combining the unique electrical properties of nanoscale gaps, electrical detection systems supply excellent prospects for the design of biomolecular detection devices. Over the last 10 years, increased efforts have been made to establish nanogap biosensors which allow production of nanogap at reduced operation time and cost, as well as large-scale integrability, easy read-out and higher sensitivity.

It is important to point out that reviews dealing with nanogap issues mainly concentrate on the fabrication of nanogap electrodes[5], nanostructured-based electrical biosensors[7], and nanogap dielectric biosensor for label free DNA hybridization detection[6]. Very few papers have been written not only describing important contributions but also analysizing their possible properties. Here we review the progress so far in electrical nanogap biosensors, we survey available processing types suitable for the detection of different biomolecules, we discuss the principles of operation of electrical biosensing, and consider major strategies for enhancing their performance and/or key challenges and opportunities at their current stages and their further development.

Planar nanogap devices for biosensing

Label-free biosensing

Planar nanogap can be defined as both electrodes face each other horizontally in the device configuration (Fig. 1a). Some early reports were from UC Berkeley[8-11]. A nanogap was fabricated in which two polysilicon electrodes were separated from each other by a 50-100 nm

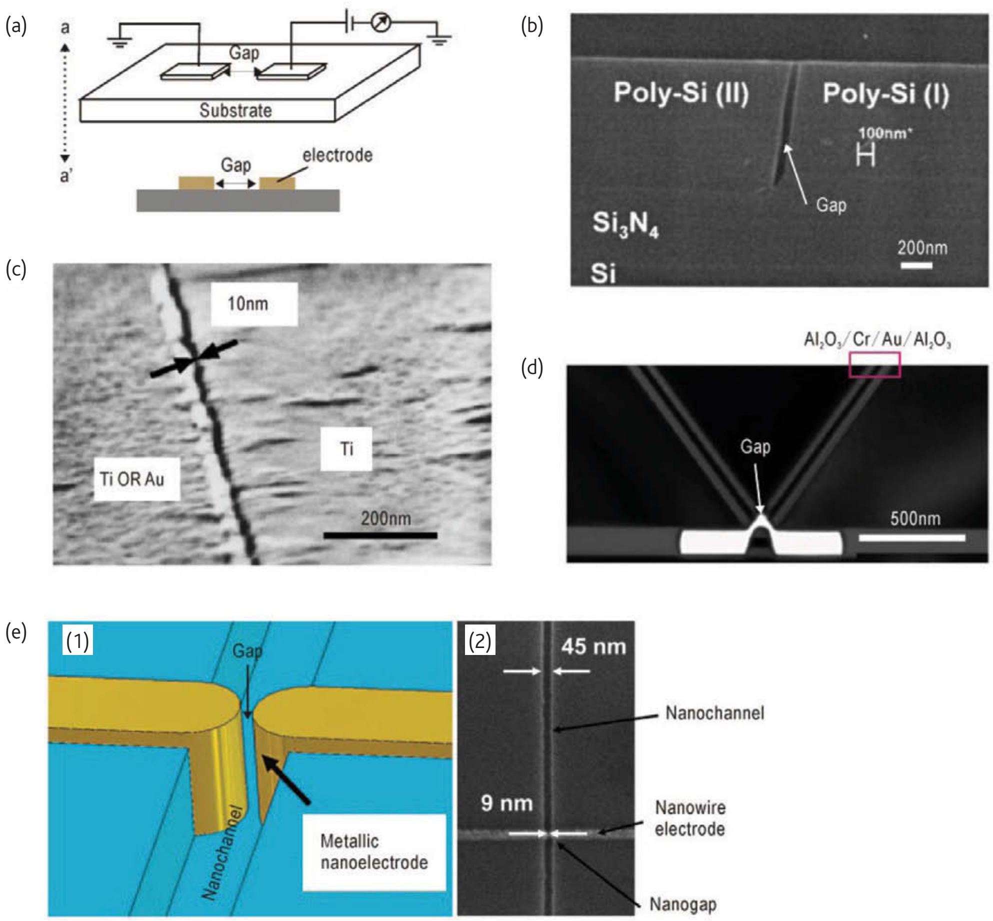

Fig. 1 Label-free planar nanogap devices for biosensing. a) Three-dimensional schematic and cross-section showing a planar nanogap structure. b) Nanogap using polysilicon as electrodes[11]. c) Nanaogap using two Ti electrodes or Ti/Au electrodes[15,16]. d) Trapezoid-shaped nanogap device fabricated using a silicon anisotropic wet etching technique on a silicon-on-insulator wafer[20]. e) A DNA detector with a nanogap inside a nanofluidic channel[21]. (1) A pair of metallic nanowires is formed across the nanochannel with a sub-10 nm breaking gap in the channel. (2) Top-view SEM image of a nanogap detector including a fluidic channel.