Analytica Chimica Acta 988 (2017) 1–16

Contents lists available at ScienceDirect

Analytica Chimica Acta

journal homepage: www.elsevier.com/locate/aca

Review

# Review: Novel sensing strategies for bacterial detection based on active and passive methods driven by external field

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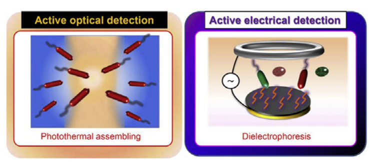
## HIGHLIGHTS

- Recent progress in active and passive detection methods of bacteria by external fields is reviewed.
- Trends in passive optical and electrical detection methods of bacteria are covered.
- Photothermal assembling for rapid bacterial detection is discussed as an active optical method.
- Dielectrophoretic selective detection of bacteria with molecular imprinting is described as an active electrical method.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 10 August 2016
Received in revised form
15 July 2017
Accepted 17 July 2017
Available online 21 July 2017

*Keywords:*
Bacteria
Optical detection
Electrochemical detection
Molecular imprint

## ABSTRACT

For sustainable human life, biosensing systems for contaminants or disease-causing bacteria are crucial for food security, environmental improvement, and disease prevention. With an aim of enhancing the sensitivity and detection speed, many researchers have developed efficient detection methods for target bacteria. In this review, we discuss recent topics related to active and passive bacterial detection methods, including (1) optical approaches with unique functional nano- and micro-structures, and (2) electrical approaches involving mechanical modulation and electrochemical reactions. Particularly, we discuss the prospects in the development of label-free, rapid, and highly sensitive biosensors based on active detection principles with light-induced dynamics, in conjunction with dielectrophoresis-induced selective trapping.



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http://dx.doi.org/10.1016/j.aca.2017.07.034
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## 1. Introduction

Various culture methods with established accuracies are used for bacterial detection. Highly sensitive detection methods for a single bacterium are theoretically possible, except when the target bacterial species cannot be cultured [1,2]. Since the bacterium can be obtained as a clone, it can be qualitatively examined for bacterial strain identification and pathogenic analysis after cloning [3]. In addition, bacteria change continuously at the genetic level depending on the surrounding environment, and thus slightly differ from each other, even between cells of the same strain [4]. A culture method that enables the isolation and preservation of a bacterium may be the most reliable and accurate method [5–7]. However, accurate employment of culture methods requires a substantial amount of time and a trained technician who is very knowledgeable about bacteria. Disadvantages of these methods include the complexity of the process and time required to obtain the results, which is typically 24–48 h.

Various rapid detection methods have been developed to overcome these limitations. For example, a variety of optical detection methods based on spectroscopy and microscopy in static and flow systems with fluorescent labeling, periodic dielectric microstructures (photonic crystals), metallic nanostructures, as well as electrical approaches based on physical chemistry with direct electrochemical method, piezoelectric mechanical method, and mass analysis have been reported. Recently, to enhance detection sensitivity and reduce detection time, the "active" guiding of the target bacteria to the observation region by optical and electrical external fields has gained attention in addition to the aforementioned "passive" specific binding with molecular recognition mechanisms in the absence of an external field (Fig. 1). Relevant information of papers published from 2010 to 2015 related to the optical- and electric-field-assisted detection are presented in Fig. 2a–c. Bacterial detection is most often based on fluorescent and electrochemical principles, with other optical methods (plasmon, luminescence, photonic crystal, optofluidic, photothermal etc.) and the other electrical methods (piezoelectric, quartz crystal microbalance (QCM), dielectrophoresis etc.). The number of passive methods has remained nearly constant over the years. On the other hand, active electrical and optical methods that were first described in 2010. While still few in number and in the early stages of development, these methods are expected to become influential with time and should spur new breakthroughs. The number of publications for various types of bacteria is summarized in Fig. 2d and e. The number of papers on the gram-negative bacteria is double that on the gram-positive bacteria. In addition, markedly more publications have focused on the detection of bacilli than spherical bacteria.

In this review, we introduce various studies related to bacterial sensors, focusing on optical and electrical approaches in Chapters 2

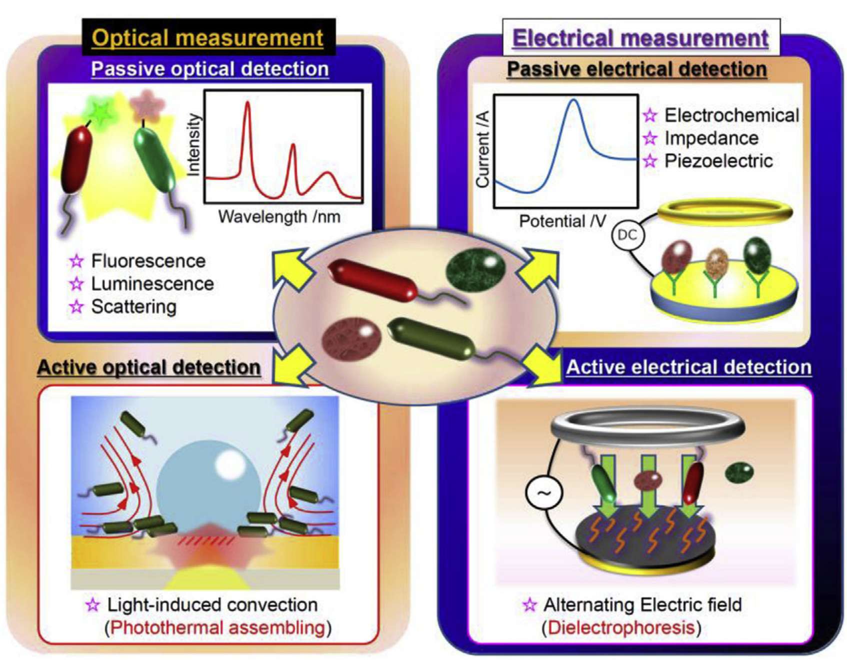


**Fig. 1.** Schematic representation of biosensors based on optical and electrical measurements and new strategies of photothermal assembling and bacterial imprinting.