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Review

Strategies to improve the analytical features of microfluidic methods using nanomaterials

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ABSTRACT

The development of microfluidic systems has made available new high-throughput methods with features essential to miniaturization, such as low consumption of sample and reagents, easy manipulation and reduction in analysis time. However, in addition to these advantages, miniaturized methods are frequently limited by low levels of the two desirable basic properties of sensitivity and selectivity. The use of nanomaterials (NMs) in microfluidic methods is a recent trend, mainly using their special physical and chemical features to improve sensitivity and selectivity.

This review reports on a systematic study of the usefulness of NMs in the different steps of the analytical process for microfluidic systems: preconcentration, separation, reaction and detection. We illustrate the advantages offered by NMs in each of these steps with representative recent examples that highlight the scientific interest in widening the use of nanotechnology in microfluidic methods. Also, we briefly discuss the use of NMs in paper-microfluidic methods.

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1. Introduction

Microfluidic systems constitute a clear example of the advances achieved in one of the main trends in analytical chemistry, the development of miniaturized analytical systems. A microfluidic device involves manipulation of fluids in channels with dimensions of tens of micrometers and, usually, requires three basic components: a system to introduce samples and reagents; a system for moving the fluids around on the chip; and, a detector. The increasing interest in the use of microfluidics for analytical purposes is the result of their desirable features, such as low consumption of samples and reagents, and rapid detection time. Chemical, biochemical and genetic analysis, drug screening and chemical synthesis are examples of the application areas of microfluidic methods. However, in spite of the advantages of these methods, they also show limitations in their sensitivity and selectivity, which restrict their applications in the analysis of real samples. For example, a frequent constraint inherent to miniaturization is the low signal-to-noise ratio obtained and the low detectability of the analytical signals.

The use of nanomaterials (NMs) in analytical microfluidic methods is a recent strategy that is useful to improve sensitivity and selectivity. This positive effect has been demonstrated in the main steps of the analytical process. Thus, different types of NMs have been used {e.g., to improve the separation in microchip electrophoretic (MCE) methods [1] or to increase the analytical signal in the detection step using optical or electrochemical systems [2,3]}. However, the potential of NMs to extend the practical application of microfluidic systems in different analytical areas has scarcely been discussed.

Fig. 1 shows the evolution of the number of articles involving microfluidic methods published in the main analytical journals in the past 12 years, and those that describe their application to the analysis of real samples. As can be seen, there is an exponential growth of publications up to 2009, and then the number of publications is maintained at a fairly constant level. Fig. 1 also shows the evolution of the number of articles that include the use of NMs. Although this number is not high, a gradual increase can be observed, reaching ~16% in the past year. It is also worth noting that ~50% of analytical microfluidic methods developed in the absence or in the presence of NMs include their application to the analysis of real samples.

In spite of the relatively low incidence of NMs in microfluidic methods, there is a clear trend to use the special properties of NMs in order to increase, mainly, the selectivity and the sensitivity of these methods. As Fig. 2 shows, the versatility of NMs allows their applications in the preconcentration, separation, reaction and detection steps developed for microfluidic systems. We give below examples of their usefulness in these steps. Although most of these applications (~60%) have focused on improving the detection step, NMs also contributed to solving specific problems in the other steps of the analytical process.

This review presents a critical overview and a systematic discussion of the outstanding role of NMs in the steps of the analytical process developed for microfluidic systems. It focuses on highlighting the improvement of the features of these methods in the presence of NMs and, consequently, their capability to facilitate analytical applications.

Microfluidic methods involve the use of glass or a polymer, usually poly(dimethylsiloxane) (PDMS), to fabricate the microchannels of the microfluidic device. However, recently paper was used as substrate to develop paper-based microfluidic methods. At the end of this article, we briefly discuss the advantages and the limitations of this approach, developed together with NMs, and describe some examples of their analytical usefulness.

2. Nanomaterials in the preconcentration and separation steps

The large surface area-to-volume ratio and the relatively easy functionalization are the two main properties of NMs used in these steps of the analytical process developed for microfluidic systems. A few examples described below illustrate the capability of NMs to improve the sensitivity and the selectivity using magnetic separations and MCE determinations.

2.1. Magnetic separations

Magnetic nanoparticles (MNPs) have been extensively applied as solid supports in NP-based microfluidic assays, since they can

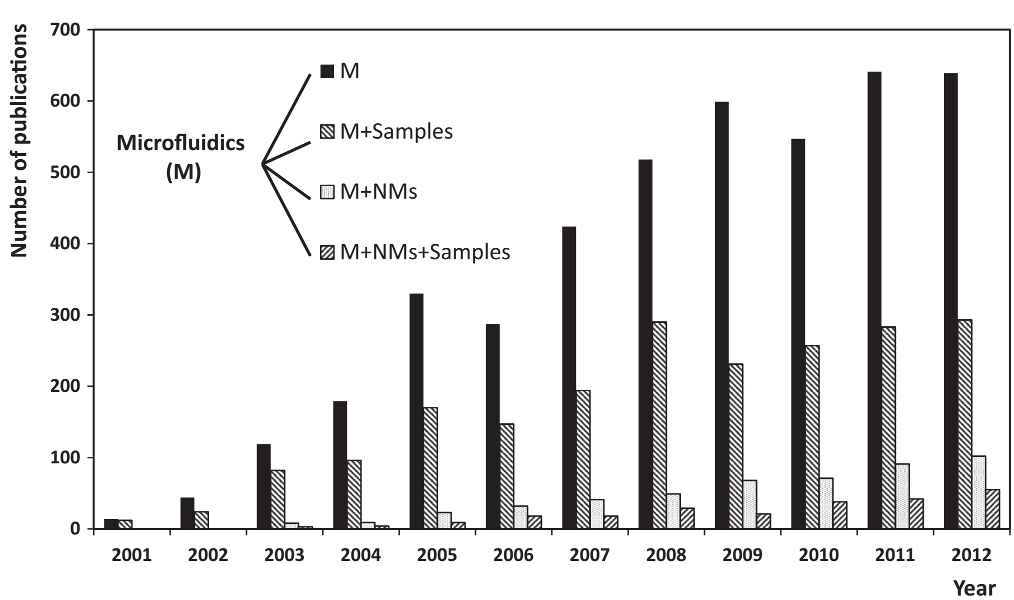

Fig. 1. Evolution of the number of articles devoted to analytical microfluidic methods, published in the main analytical journals in the past 12 years. Also shown is the number of these articles that include the use of nanomaterials (NMs) and those describing the application to the analysis of real samples, in the absence and in the presence of NMs, (Source: Scopus 2013, Elsevier B.V.).