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Microstructure devices for process intensification: Influence of manufacturing tolerances and design

Juergen J. Brandner*

Institute for Micro Process Engineering, Campus North, Hermann-von-Helmholtz-Platz 1, D-76344 Eggenstein-Leopoldshafen, Germany

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ABSTRACT

Process intensification by miniaturization is a common task for several fields of technology. Starting from manufacturing of electronic devices, miniaturization with the accompanying opportunities and problems gained also interest in chemistry and chemical process engineering. While the integration of enhanced functions, e.g. integrated sensors and actuators, is still under consideration, miniaturization itself has been realized in all material classes, namely metals, ceramics and polymers. First devices have been manufactured by scaling down macro-scale devices. However, manufacturing tolerances, material properties and design show much larger influence to the process than in macro scale. Many of the devices generated alike the macro ones work properly, but possibly could be optimized to a certain extend by adjusting the design and manufacturing tolerances to the special demands of miniaturization. Thus, some considerations on the design and production of devices for micro process engineering should be made to provide devices which show reproducible and controllable process behavior. The aim of the following publication is to show the importance of considerations in manufacturing tolerances and dimensions as well as design of microstructures to avoid negative influences and optimize the process characteristics of miniaturized devices. Some examples will be shown to explain the considerations presented here.

1. Introduction

In many fields of technology, process intensification is a major task to deal with. Integration of more functionality and greater flexibility as well as higher selectivity and/or higher yield is an objective for developments in communication technology as well as in mechanical, chemical and biological process engineering. The success of miniaturization in intensifying communication technology is easy to see due to the fact that the power and abilities of microelectronic equipment have increased drastically within the last decades – cellular phones and modern computer technologies are examples of this.

In terms of process engineering, the advantages of miniaturization are easy to describe. Heat and mass transfer using fluids can be greatly increased if the characteristic distances are reduced. According to (1), the mixing time t_M based on diffusion with the fluid-specific diffusion coefficient D is drastically reduced if the characteristic length x is minimized.

$$t_M = \frac{x^2}{2 \cdot D} \tag{1}$$

This is shown in Fig. 1 for nitrogen and water as sample fluids. Similar considerations hold for the heat transfer time. Finally, it can be shown that miniaturization of process engineering equipment can increase the performance of certain basic operations like heat transfer or mixing by at least one order of magnitude, sometimes even much more [1]. However, miniaturization results also in an increased sensitivity to deviations of the process parameters, including the design and properties of the process technology equipment itself.

While designing micro process engineering equipment, there are several restrictions to consider. The application is the major one, but the aspects of material, producibility and re-producibility are not much less important.

Micro process engineering equipment has to be suitably designed for manufacturing in the designated material. Assembly and sealing has to be considered besides the opportunity to generate more than only a single prototype device, which needs to take into account manufacturing tolerances to obtain the same process behavior in each device [2].

* Tel.: +49 (0)721 60823963; fax: +49 (0)721 60823186.
E-mail address: juergen.brandner@kit.edu.

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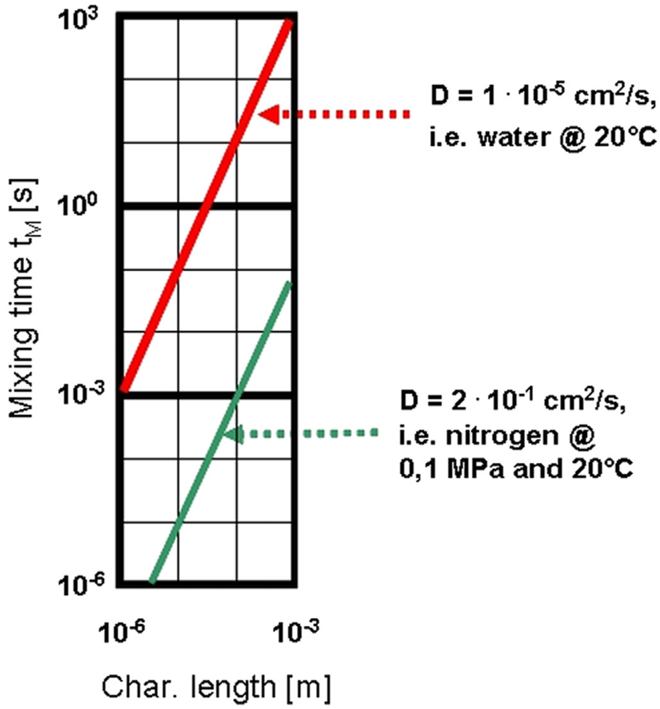

Fig. 1. Diffusion time for N_2 and water as function of the characteristic dimension.

For process engineering equipment of conventional dimensions, surface roughness is not a major task to deal with. In several applications a rough surface may lead to an increased fouling tendency, but in general, the functionality of the devices is not much changed by the surface roughness.

Surface quality and surface roughness in microstructure devices are of major importance due to two reasons: fouling and reduction of hydraulic diameter. Fouling in microstructures will very rapidly lead to malfunction of the complete device. The reduction of the hydraulic diameter due to increased surface roughness will increase the pressure drop as well as a possible mal-distribution of fluids to parallel microstructures.

Aside of the considerations for design and manufacturing, measurement and control of the process parameters are essential to run them in a desired way. Therefore, the choice of measurement method and sensors as well as the correct positioning of those within the microstructure process equipment is a relatively complex task to deal with.

2. Influences of material, manufacturing and design

2.1. Material influences

Material properties have to be considered first when thinking of a certain application to be run in microstructure devices. The questions arising here are for mechanical stability, chemical or corrosion resistance, thermal and electrical properties as well as the way of manufacturing. The choice of material also defines the manufacturing method – some materials cannot be used for, i.e., precision machining [2,3].

2.2. Manufacturing influences

Manufacturing influences can be classified as surface quality (or roughness) and manufacturing precision (or tolerances).

High surface roughness may increase the heat transfer, but also make a device more prone to fouling and generation of deposit layers. Fig. 2 shows examples of structures manufactured by laser machining (Fig. 2a), wet chemical etching (Fig. 2b) and precision milling (Fig. 2c). In all three cases, the base material was stainless steel (1.4310 for laser machining, and 1.4301 for etching and mechanical machining). For the laser machining, a Nd:YAG laser (355 nm wavelength) was used in melt ejection mode (see [2,4]). Etching was performed using an aqueous solution of $FeCl_3$, while the precision machining was done with a hard metal tool on

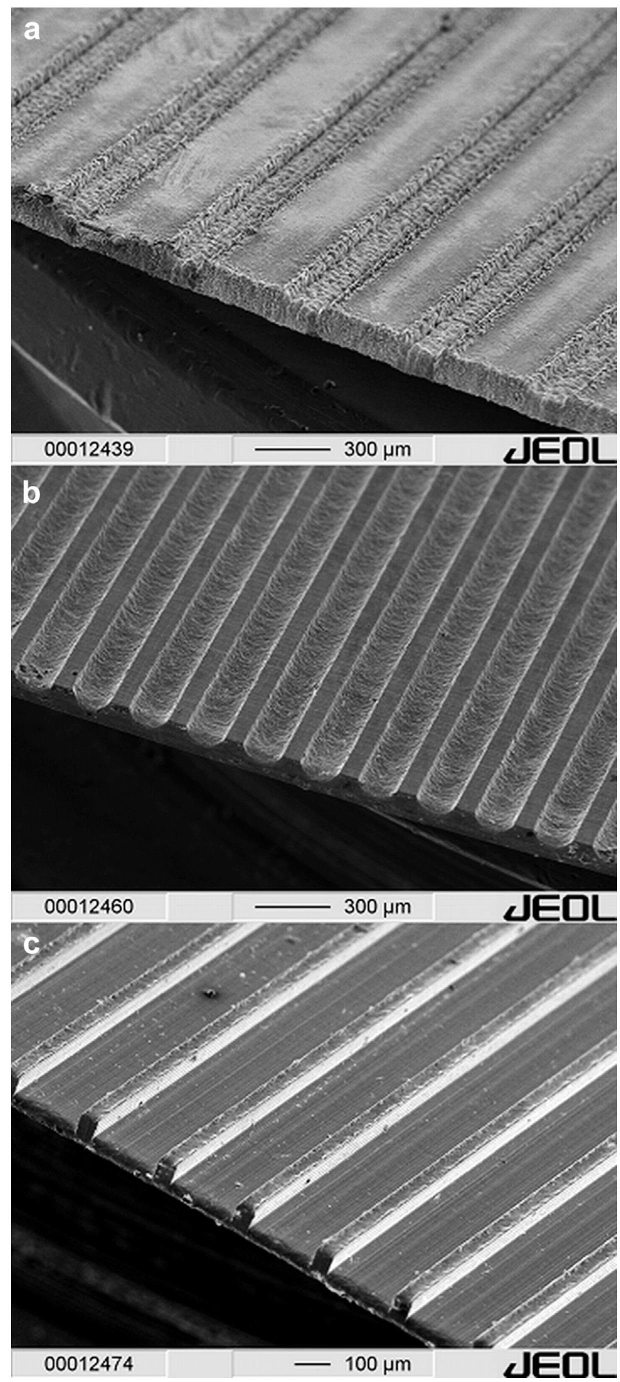

Fig. 2. SEM pictures of micro channels manufactured by laser machining (2a, top), wet chemical etching (2b, middle) and precision milling (2c, bottom). Obviously the parameters for laser machining have not been chosen correctly.