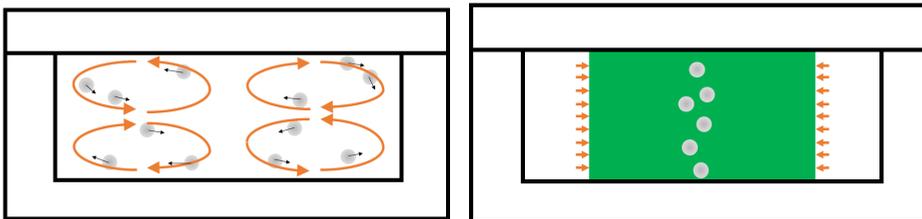


## How to manipulate bacteria using sound

**T**his thesis deals with acoustophoresis, i.e. how ultrasound can be used to manipulate and separate microscopic particles and bacteria in an extremely small microchannel. Handling of such small particles is useful when you want to separate one type of cells from another, for example red blood cells from tumor cells.

Separation channels are produced in silicon. The channel is sealed by a glass lid, and holes are made for the inlet and outlet of liquids. On the bottom of the silicon, a piezoelectric transducer, which is a sound producing element, is glued. The vibrations of the sound spread in the chip and result in resonances in the channel. When microparticles are in this channel, the sound scatters on the particle. This results in an acoustic force, known as the acoustic radiation force, pushing the particles to the centre of the channel. The magnitude of the force depends on the particle properties (size, density, compressibility). For one particle type the movement to the centre is faster than for another particle type. This difference in velocity can be used to separate the particle types from each other. At the end of the channel, the flow is split into three branches, one in the centre and two at the side. The particles with a fast movement to the centre will be in the central outlet at the end of the channel, while the particle with a slower movement will be in one of the two side branches.

Because a resonance is achieved in the channel, a specific type of streaming is generated in the channel as well. The circular streaming rolls also have an effect on the particle movement, which limits the use of acoustophoresis. If the effect of the acoustic streaming is dominant over the acoustic radiation force, which is the case for very small particles ( $< 2 \mu\text{m}$  diameter), the particles are dragged with the streaming rolls and cannot be focused to the centre of the channel (figure (a)). This means that handling of particles such as bacteria is very hard with acoustophoresis.



(a) Medium with homogeneous properties (b) Medium with inhomogeneous properties

Usually the particles are suspended in a medium with the same acoustic properties. In this thesis we changed the acoustic properties of a part of the medium, i.e. we introduced an inhomogeneous medium in the channel (figure (b)). The inhomogeneous medium generates extra acoustic forces on the medium itself which suppress the generation of acoustic streaming for a short period. With this method it is possible to circumvent the size limit for acoustophoresis with a homogeneous medium. We showed that in this period of suppressed acoustic streaming, it is possible to manipulate bacteria, or separate different particles from each other. This is a promising discovery which can lead the use of acoustophoresis to new application areas. Using this technique it may be possible to wash, sort, concentrate or separate bacteria, or other sub-micron (bio)particles.