Optical tweezers for trapping in a complex microfluidic environment.

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Optical tweezers (OT) are tools to manipulate small objects without direct contact. In this work we present the development of an OT for the trapping of particles in a microfluidic channel, which is embedded in the bore of a high field superconducting magnet. The environment imposes a variety of spatial and operational constraints that has been incorporated into our optical design. We also present the experimental verification of the optical trapping function.

1 Introduction

OT allows for the precise 3D manipulation of the position and orientation of microscopic objects. Due to the absence of physical contact between the trapped object and the gripping tool, no adhesive forces occur, and an object is easily released simply by lowering the laser power.

In order to investigate the chemical structure of cells, organisms, small objects, or a liquid sample, nuclear magnetic resonance spectroscopy (NMR) is the measurement method of choice.

In this work we combine NMR magnet and an OT to achieve higher resolution NMR spectra with increased signal-to-noise ratio (SNR).

2 Demands on and constrains for the OT

The NMR spectroscopy is based on applying a high magnetic field to the material under investigation. Due to the magnetic moment of existing atoms, the spins of nuclei in the sample align to the applied field. If this alignment is manipulated by an additional radiofrequency magnetic field, which can be introduced for instance by an electrical coil, the atoms start a precession movement. After excitation, the achieved nutation in turn induces a radiofrequency signal, which encodes information of the nucleus, its chemical bonds, and the different atoms in the immediate vicinity. More details about NMR can be found in several textbooks [1, 2].

The NMR SNR stands in direct relation to the strength of the magnetic field (B_0) as well as its homogeneity. Huge effort is spent to provide a stable and homogeneous field at the region of interest. The position of the object should be precisely maintained over the whole measurement process. These facts, along with the compatibility of the optical system components with the high magnetic field, the conservation of field homogeneity by avoiding susceptibility jumps, and the stability of the objects within the magnet, are the main requirements to be imposed on an OT.

The OT also has to be integrated in the vertically oriented bore of a superconducting magnet, which sets a limit for the outer dimension of the optical system (see figure 1 top). Furthermore, the OT has to be optically linked to a microfluidic channel consisting of several transparent material layers (see figure 1 bottom).

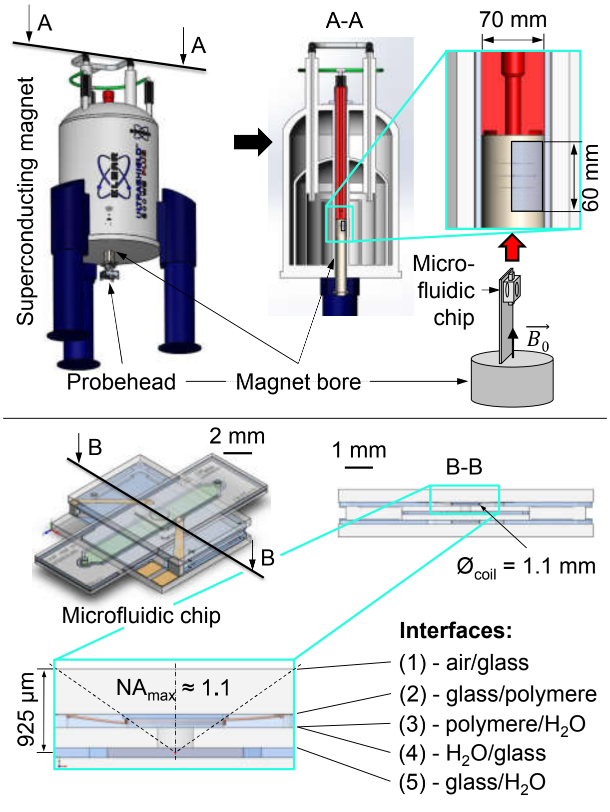

Fig. 1 *Schematic of the superconducting magnet (top) and the microfluidic channel structure (bottom) [3].*

The bore diameter is 70 mm and the available space for the optical system is indicated by the grey colored rectangle in figure 1 top right, a semi-cylindrical volume of 60 mm in height. The other half of the

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volume is occupied by the probehead and the microfluidic chip. The chip contains the liquid medium and the object to be optically trapped. Since the chip is mounted on an opaque probe head, the optical accessibility is limited to one side. In addition, a non-transparent coil limits the NA of the optical system. These geometrical constrains have to be considered during the design phase of the optical system.

3 Development of the OT and Results

Considering the boundary conditions and requirements described above and as demonstrated in previous work [4], optical trapping is performed by a parabolic shaped component to focus the light and a refractive double axicon for beam shaping, in order to increase the optical trapping performance. In addition, a right angled prism is used to deflect the laser beam by 90°.

As illustrated in figure 2 left, a Gaussian beam is incident on the tip of a double axicon. Refraction of light through the first conical surface shapes the incident light into a ring distribution. The ring of light propagates divergently along the optical axis of the axicon until it intersects the second conical surface of the axicon where it is collimated due to total internal reflection (TIR). After the beam is deflected by 90° using a right angled prism, the ring is focused inside the microfluidic chip by the parabolically shaped glass-air surface, again by TIR.

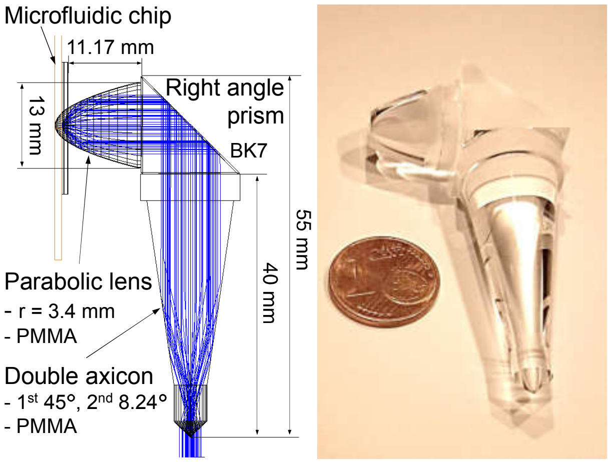

Fig. 2 *Final design of the OT (left) and photographic image of the assembled optical trapping system (right).*

The focal point of the parabolic lens is located in the center of the microfluidic channel where the optical trap is formed. Ray optics based force simulations [5] predict stable trapping conditions with an optical trapping force of 15.7 pN (parameters: laser power 50 mW, spherical object of 10 μm in diameter, material glass, liquid environment).

Once the optical components were fabricated externally, we characterized them using vertical scanning interferometry. For all optically active surfaces we measured a surface roughness (R_a) between 31 nm and 10 nm.

The double axicon is fixed to the right angle prism on one of its flat faces through the application of optical adhesive. The parabolic lens is fixed to the other side of the prism, while alignment through all three objects within the system is precisely maintained. This single and well-aligned optical element represents the complete OT.

To investigate optical trapping experimentally, the OT is integrated in an optical setup described previously [4]. Spherical fused silica particles of 10 μm diameter are targeted for trapping. With the optical system we trapped and held glass particles over long periods (hours). The minimum laser power required for stable optical trapping is 130 $\pm$ 10 mW. The results were proved to be reproducible.

4 Conclusion

We developed an OT for the manipulation of microscopic particles within a microfluidic channel. Based on a ray optical force simulation, the OT was optimized for maximum trapping performance. Once the optical components were characterized and assembled, we experimentally verified the proper function of the OT. The next steps are the integration of the OT in the NMR setup to investigate the benefit of the combination of NMR and optical manipulation.

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