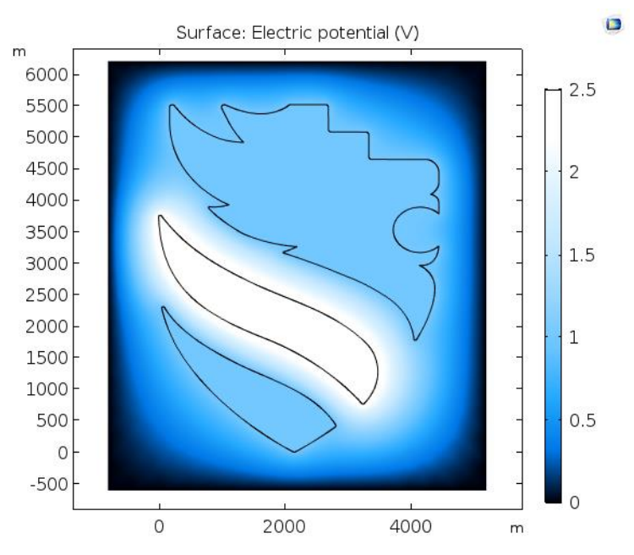
# Simulation of Integrated Sensors Based on Cold Atom Technology



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**INTRODUCTION**: Cold atom based technology is an interesting platform to create novel quantum sensing devices for inertia, gravity or magnetic fields [1]. Here we will show how chip-based cold atom traps can be modelled using COMSOL® to allow the design of integrated sensor systems.

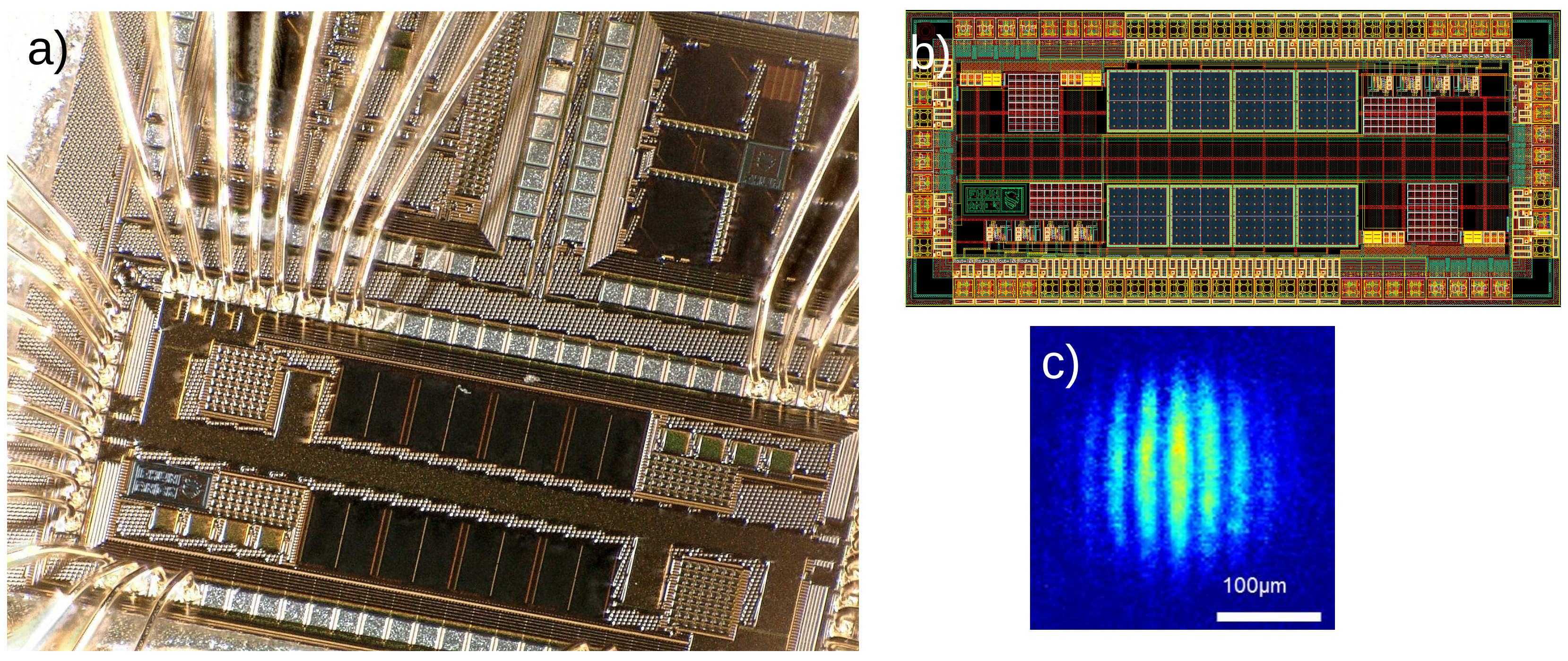

**Figure 1**. Layout (a) and Microscope image of finished chip (b) and matter wave interferometry (c) (courtesy Schmiedmayer Group, Vienna)

**COMPUTATIONAL METHODS:** Chip based traps allow manipulation of ultra cold atoms using magnetic fields and their gradients [2]. Precisely atoms in a low field seeking state ($m_f g_f > 0$) will assemble at the position of a local minimum of the magnetic field present. Such a minimum in the field can be generated using a chip based wire and an offset field $\boldsymbol{B}_{ext}$. Ideally – assuming an infinitely thin wire – this trap will form at a distance of $h = 2I/B_{ext}$ from the wire, where I is the current in the wire. We realize this in COMSOL® by solving

$$\nabla \times \boldsymbol{H} = \boldsymbol{J}$$

$$\nabla \times \boldsymbol{A} = \boldsymbol{B}$$

$$\text{and } \boldsymbol{B} = \mu_0 \mu_r \boldsymbol{H} + \boldsymbol{B}_{ext}$$

on a 2D domain.

The finite size of a real wire will result in a deviation the position of the center of the trap (see figure 1 &2). By adding two additional wires on the chip with currents counter-propagating the central wire, it becomes possible to omit the external magnetic field.

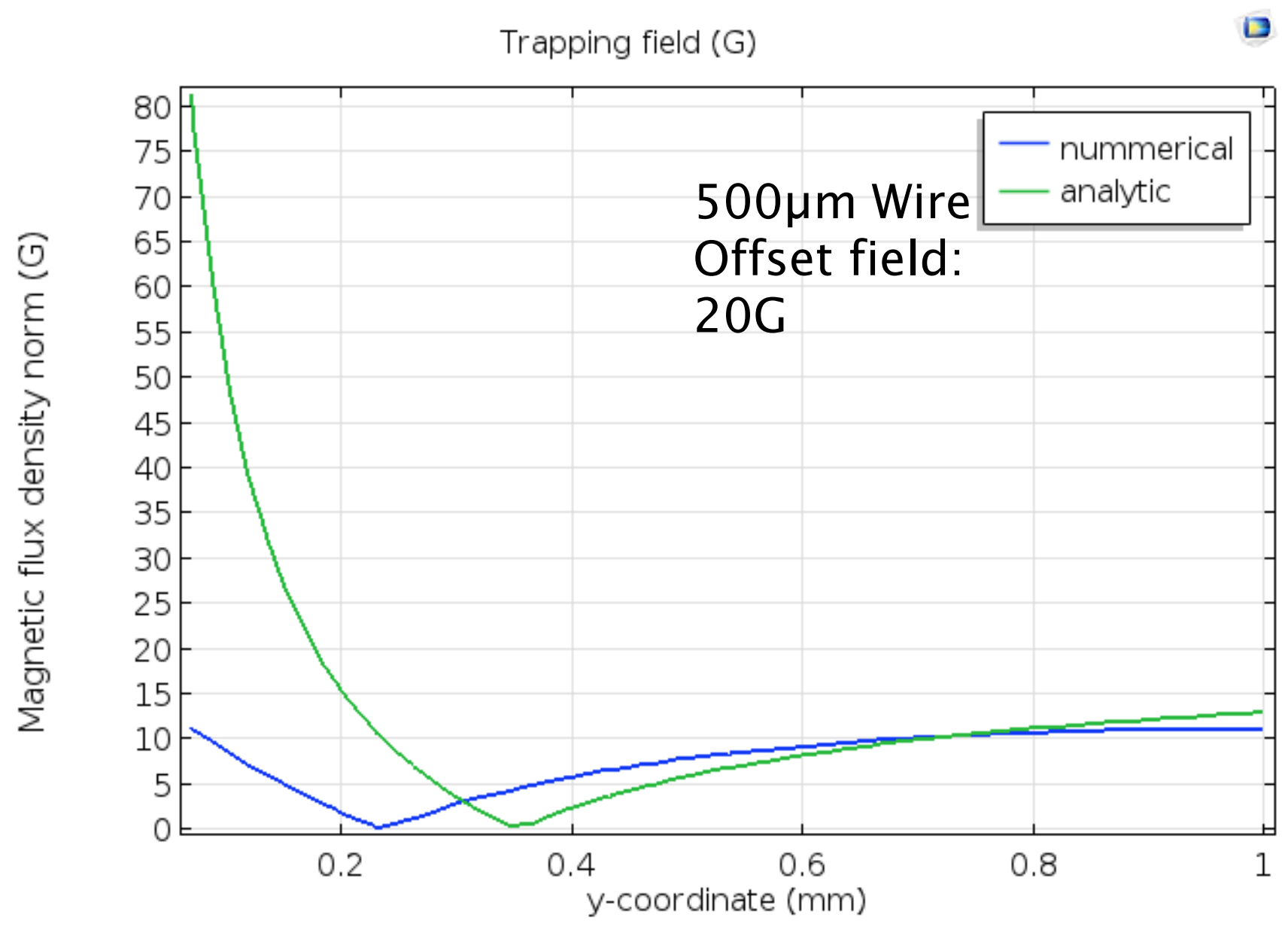

**Figure 2**. Finite size effect of the trapping wire. The position as well as the gradient of trap is altered.

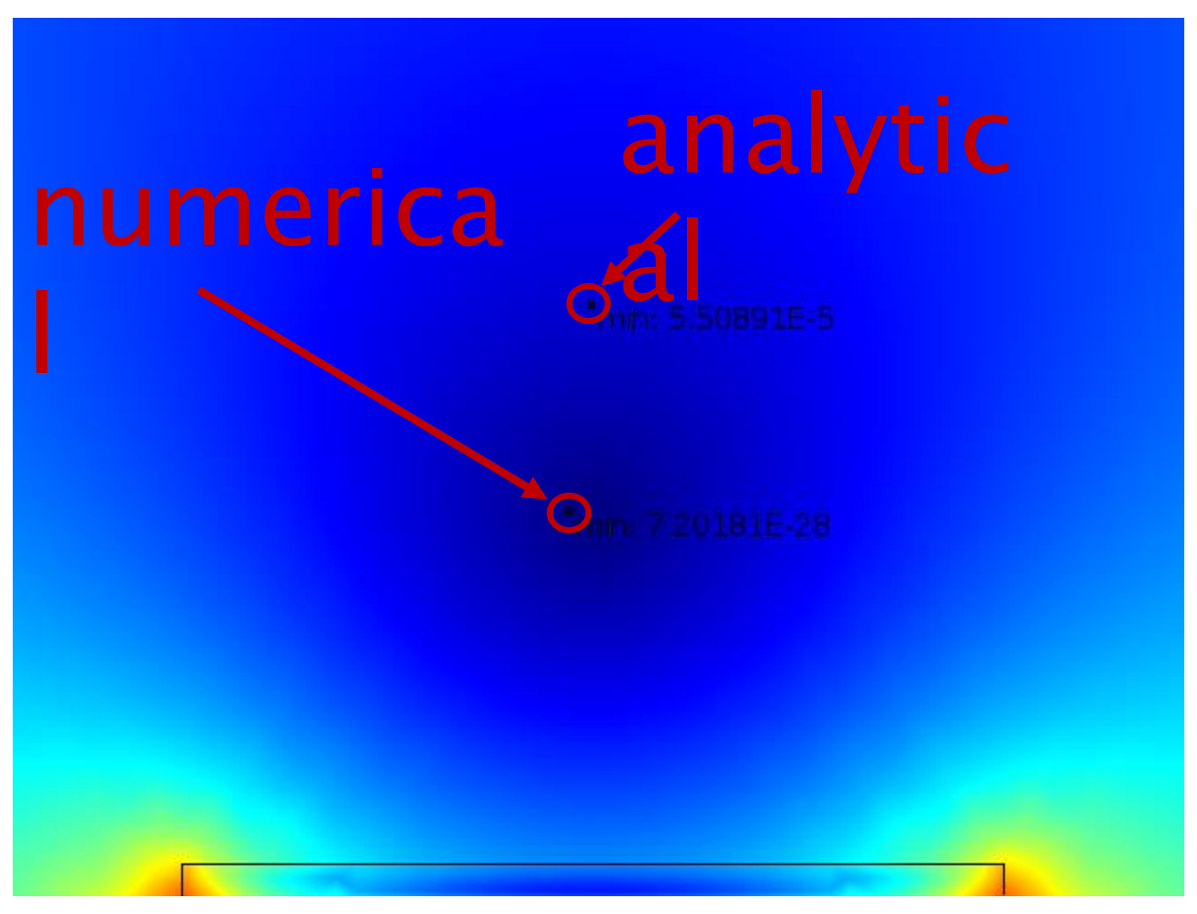

**Figure 3**. Comparison of the magentic field minima (analytical vs. numerical)

This will lead to a further integration of the setup, without disturbing the functionality. As shown in figure 4 the trap position can be adjusted by varying the current ratio of side and central wire.

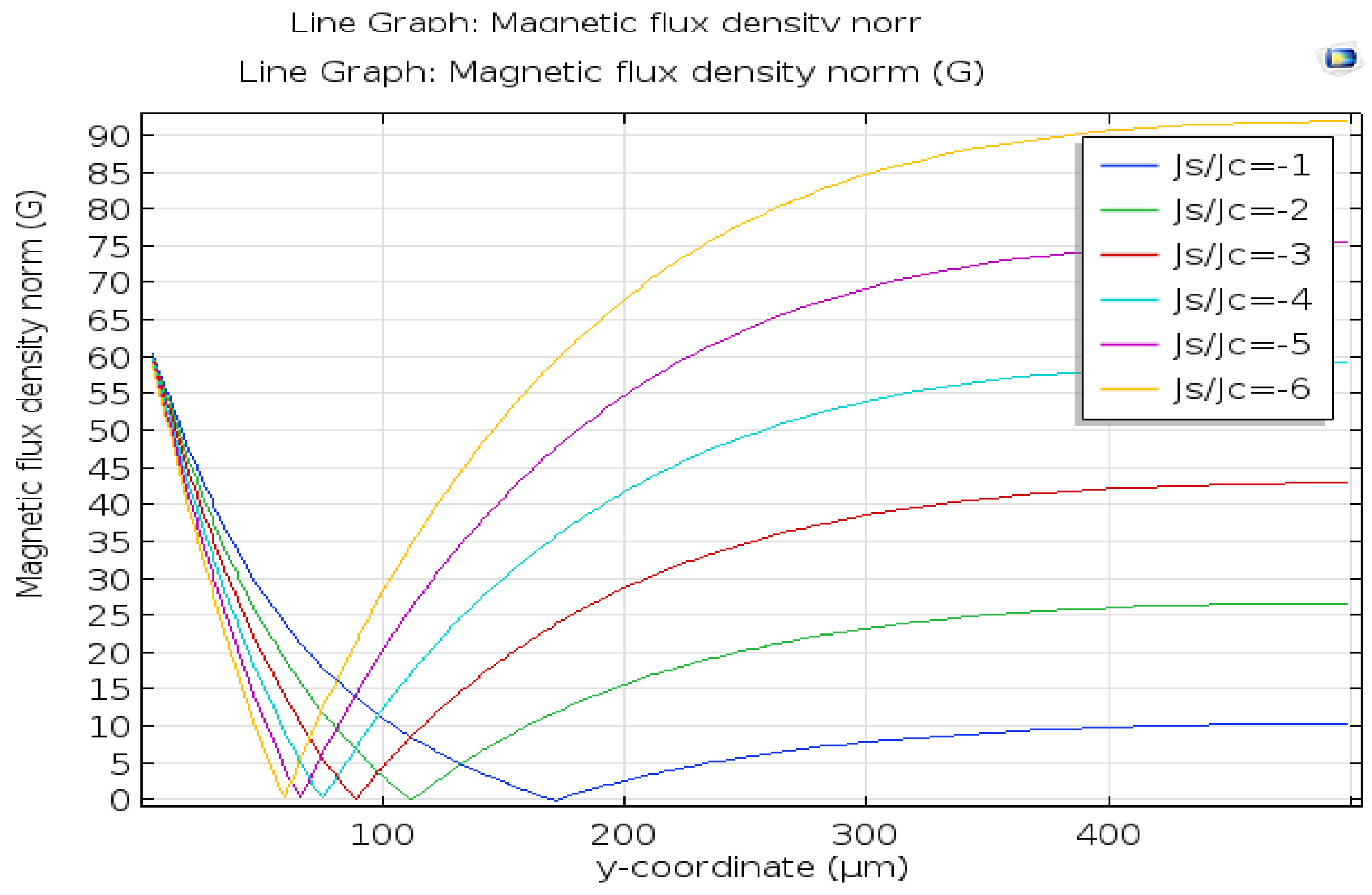

**Figure 4**. Dependence of the trap position on the current ratio between central (Jc) and side wire (Js)

**RESULTS**: The precise knowledge of the magnetic filed configuration allows to solve the Schrödinger equation

$$\left[-\frac{\hbar^2}{2m}\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)+V(x,y)\right]\psi(x,y) = E\psi(x,y)$$

with $V \approx m_f g_f \mu_B |\boldsymbol{B}|$. Figure 5 shows the forming wave function for Rb87 within the trap. Adaptive mesh adjustment of the Eigenvalue computation allows bridging the different aspect ratios of the problem easily.

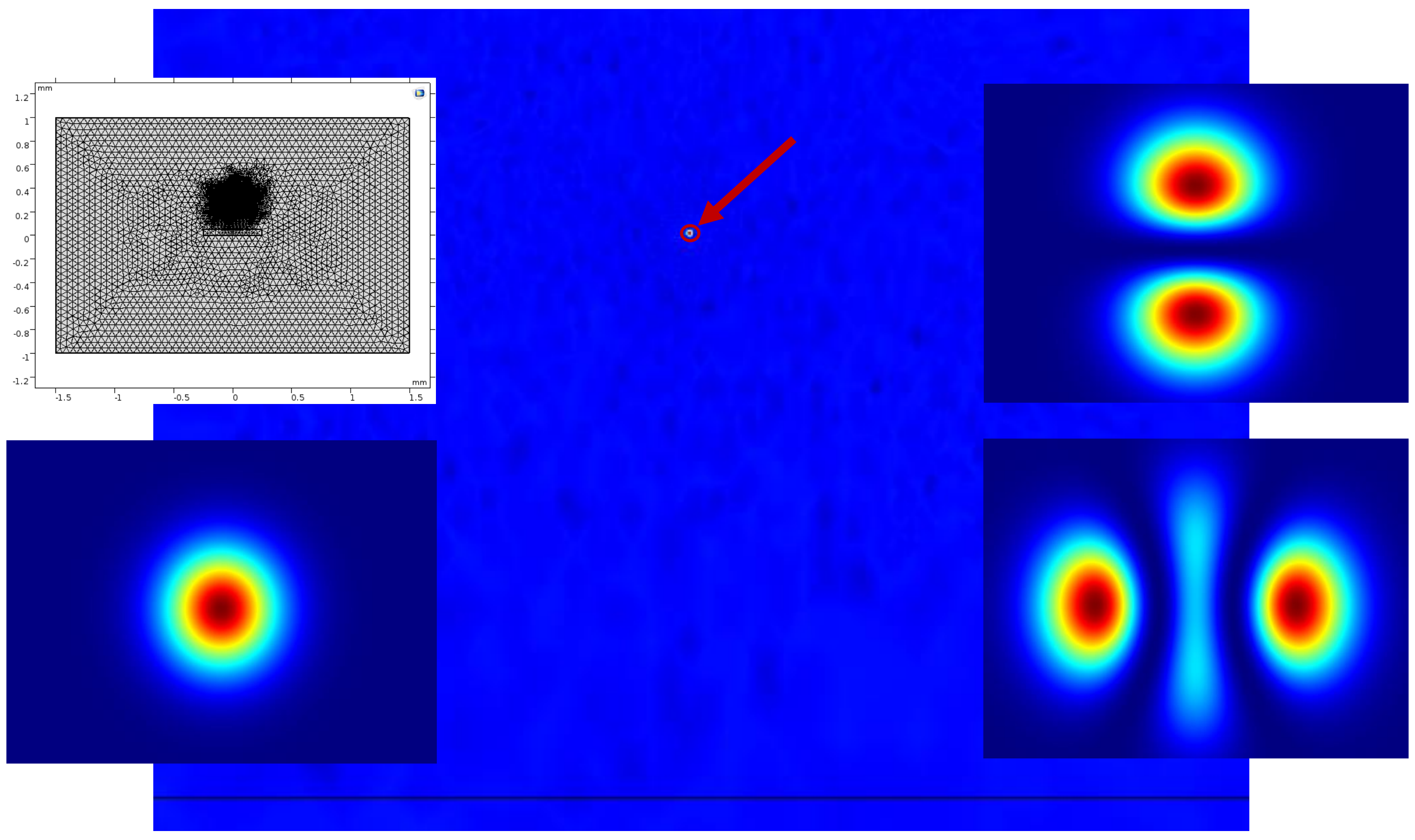

**Figure 5**. Solution of the Schrödinger Equation

**CONCLUSIONS**: It was shown that the for the realization of interferometric quantum sensors necessary computation of the wave function of cold atoms within a chip based magnetic trap can be simulated efficiently using COMSOL®. This opens the pathway to more complicated structures based on CMOS technology as logic and optical elements.

**REFERENCES**:

1. Keil M et al. 15 Years of cold matter on a chip, J. of Mod. Optics, 63:18, 1840-1885
2. Folman R. Microscopic atom optics, Advances in Atomic, Molecular, and Optical Physics, 48, 263-356 (2002)