Design And Simulation Of An Additive Manufactured Microwave Cavity For Compact Cold Atom Clocks

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Abstract

We present the design and performance simulations for a microwave cavity for use in novel compact cold atom atomic clocks. Design goals for such a microwave cavity are a resonance frequency at the Rubidium ground-state transition frequency of 6.835 GHz, combined with a moderate quality factor (100) and a small overall size. The overall clock approach is described in [1] and features cooling and trapping of the Rb atomic sample inside the cavity volume, using a single laser beam combined with an optical diffraction grating for creation of a tetrahedral optical beam geometry for laser cooling and trapping [2].

In the selected cavity design we employ a loop-gap resonator (LGR) geometry [2] implemented in a 4-electrode structure, see Figure 1. This approach allows to reduce the overall size of the cavity resonator to below the 4.4 cm wavelength of the 6.8 GHz resonance frequency while maintaining an excellent field uniformity and homogeneity over a large volume inside the resonator. The LGR's precise electrode structure is critical for meeting the cavity's resonance frequency and overall performance, and it can be challenging to manufacture and assemble using classical metal machining techniques. Therefore, we here present a cavity design, simulation and realization of the critical electrode structure by additive manufacturing of aluminum alloy (selective laser melting, SLM).

The simulations were performed using the COMSOL Multiphysics® software and the RF Module, notably the eigenmode and frequency domain solvers. In a first step, these tools allowed to study the dependence of main cavity properties such as resonance frequency and distance to next neighboring modes on the cavity geometry, notably on the electrode thickness t and gap width w. Furthermore, two Figures of Merit were defined and evaluated for the studied geometries, that quantify the homogeneity (constant Hz value) and uniformity (parallelism of H to the central cavity z-axis) of the microwave magnetic field H over the relevant central volume of the cavity. Figure 2 shows the simulation result for the Hz field component for the final selected geometry, showing a highly homogeneous Hz field over the central cavity region.

Comparison of the simulated S11 spectra with those measured on cavities additively manufactured in aluminum shows excellent agreement between simulation and measurement. First measurements performed on the cavity operated in an atomic clock setup indicate a very good field homogeneity and uniformity.

Reference

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[2] E. Batori, A. Bregazzi, B. Lewis, P. F. Griffin, E. Riis, G. Mileti, C. Affolderbach, “An additive-manufactured microwave cavity for a compact cold-atom clock”. Journal of Applied Physics 133 (22), 224401 (2023). https://doi.org/10.1063/5.0151207
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Figures used in the abstract

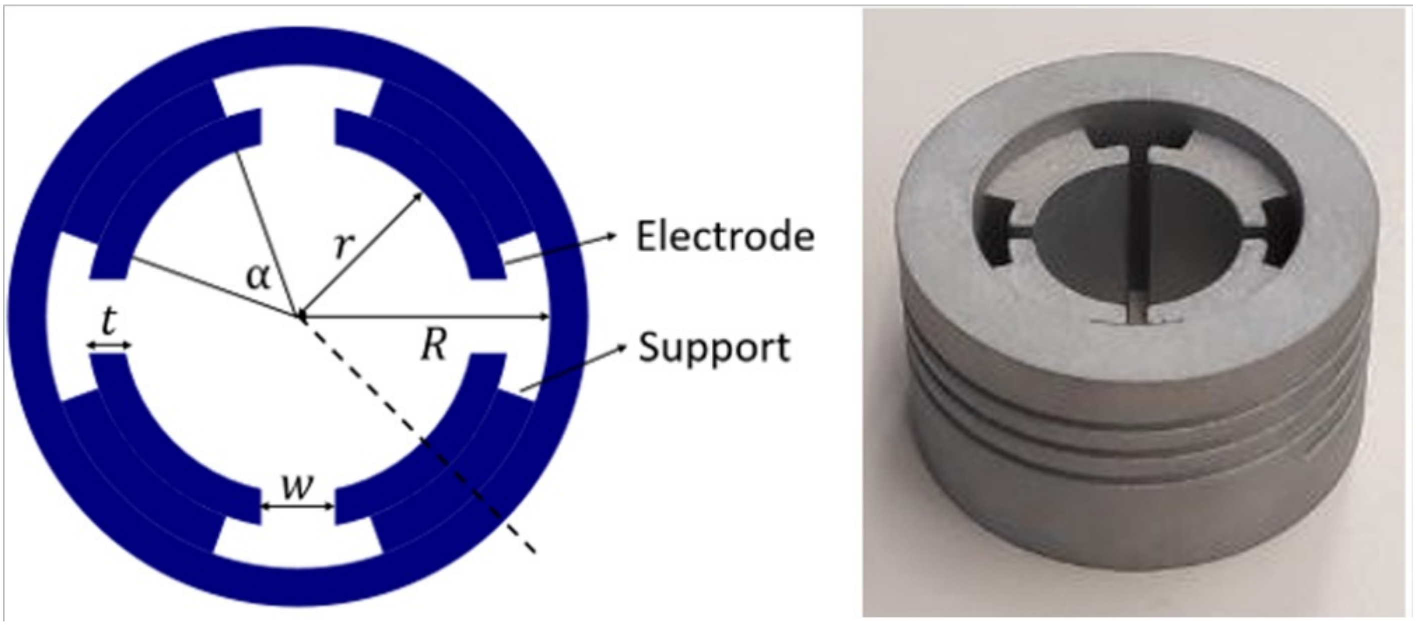

Figure 1 : Basic geometry of the LGR electrode structure in the x-y plane and additively manufactured electrode assembly [2].

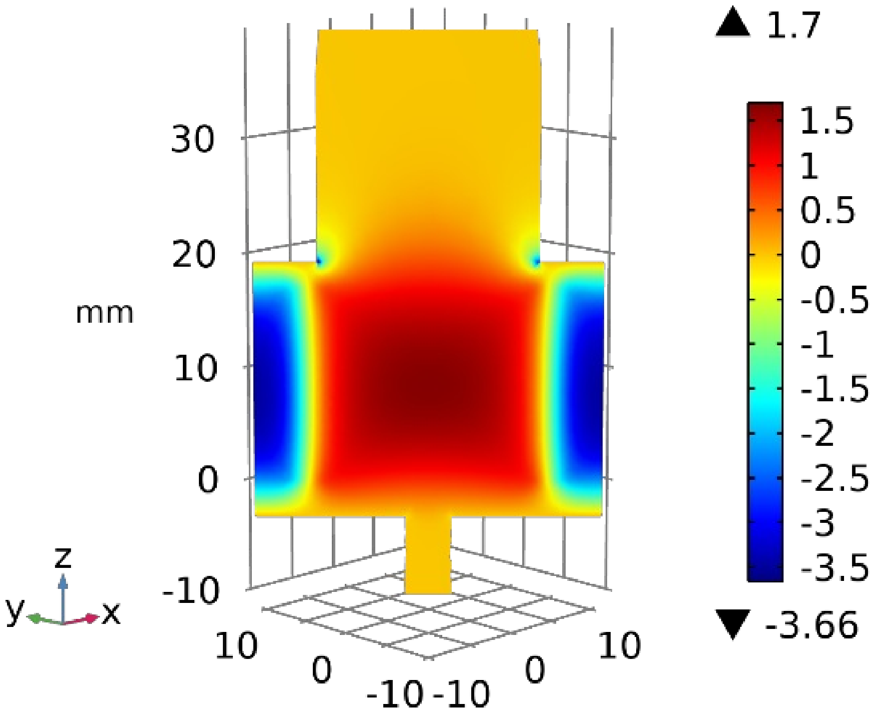

Figure 2 : 2D plot of the magnitude of the microwave magnetic field Hz component inside the cavity, normalized to its value at the position of the cold atomic cloud.