Integrating Optical Micro-Cavities with Ion Traps: Fabrication and Characterization of Fibre-based Fabry-Perot Cavities and Conductive Mirrors

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Fabry-Pérot optical cavities with small mode volumes play a crucial role in atom-based quantum information processing (QIP), as microcavities provide efficient optical interfaces in quantum networks. Trapped ions is a promising QIP platform due to their long lifetime and high-fidelity quantum gates. Fibre-based Fabry-Perot Cavities (FFPCs) have been used in ion trap cavity QED experiments [1,2]. Nonetheless, the fabrication of micro-mirrors on fibre tips with good performance was not well established despite several notable developments [3]. This is because the CO2 laser ablation used to machine the fibre tips is highly sensitive to the fluctuations of experimental parameters. Another issue when integrating an FFPC in an ion trap is that surface charges can be accumulated on the dielectric coatings of the cavity mirrors. They would disturb the trapping potential and increase the motional heating of the ions. Conductive transparent coatings on the dielectric mirrors were believed not to be useful for ultra-high finesse cavities due to their excessive optical losses.

We will first show a newly developed CO2 laser shooting technique to produce fibre-tip mirrors, based on a thorough investigation of the ablation parameters [4]. Our shooting algorithm is adaptive and in-situ, therefore robust against experimental errors. We have achieved a near-unit success rate with precise control of the mirror profiles. A cavity finesse of 150,000 has been achieved by using such mirrors. We will also re-examine the conductive transparent coatings for ultra-high finesse cavities and reveal a promising fact: The optical losses of a conductive thin film can be much lower than previously expected. If the Bragg layers are designed in a particular order, the electric field at the surface of the dielectric coating can be approximately zero due to the cavity standing wave feature. A thin conductive layer at this standing wave node causes a negligible loss. We demonstrate this principle with Indium Tin Oxide (ITO) coatings. The results show that a high cavity finesse can be achieved with an ITO coating thickness of tens of nanometers, offering enough conductivity for charge dissipation and potentially protecting the ion from heating.

Our robust FFPC fabrication and the conductive transparent coatings for cavity mirrors build a firm foundation for cavity-QED and related applications, especially for the integration of micro-cavities in charge-sensitive systems.

References

1 Phys. Rev. Lett. 124, 013602.

2 Sci Rep 7, 5556.

3 Opt. Express 24, 9839.

4 arXiv:2504.11824