# LACENET — A machine learning approach for mask generations for matter-wave lithography

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Recent progress in matter-wave experiments led to technical applications, particularly for acceleration sensing, single-particle detectors, quantum microscopes or matter-wave lithography. Thus, they act on the nanometre length scale. Consequently, the quantised nature of the object is not neglectable. In particular, the quantum vacuum has to be taken into account. Hence, the interactions between the objects are dressed by the vacuum polarisability leading to dispersion forces.

The diffraction of matter waves is based on the wave-particle duality and has the advantage that waves with sub-nanometre wavelengths can be created and thus strongly increases the resolution compared to optical devices [1]. However, the additional interactions between the matter-wave particles and the diffraction object dramatically influence the propagation of the wave [2]. We will illustrate the impact of dispersion forces on the results of diffraction experiments and demonstrate possibilities for their manipulation to enhance the contrast for matter-wave lithography applications [3].

hotolithography is a commonly applied method to create, among others, semiconductor devices. The current use is extreme-ultraviolet (EUV) photolithography that uses electromagnetic radiation with a wavelength of 13.5 nm, corresponding to an energy of 92 eV.

The ability to pattern materials at ever-smaller sizes using photolithography is driving advances in nanotechnology. When the feature size of materials is reduced to the nanoscale, individual atoms and molecules can be manipulated to dramatically alter material properties.However, the secondary electron blurring from extreme-ultraviolet photons hinders the creation patterns with a resolution below around 8 nm. An alternative approach is the use of matter waves which reaches much smaller wavelengths with a lower amount of kinetic energy. Lithography with metastable atoms has been suggested as a cost-effective, less-complex alternative to EUV lithography. In binary holography, a pattern of holes is used to approximate a Fourier transform of the desired target pattern [4]. This simple approach cannot be applied to matter-wave lithography with dielectric masks due to the additional dispersion forces. To overcome this issue, we will introduce a machine learning approach trained on the relation between mask design and interference pattern allowing an efficient estimation of a mask for a given target pattern [5]. This is of particular relevance for metastable atom lithography with binary holography masks, currently pursued in the FET-Open project Nanolace [6].

[1] C. Brand, *et al.* Ann. Phys. (Berlin) **527**, 580–591 (2015).
[2] N. Gack, *et al.* Phys. Rev. Lett. **125**, 050401 (2020).
[3] J. Fiedler, B. Holst, J. Phys. B: At. Mol. Opt. Phys. **55**, 025401 (2022).
[4] T. Nesse, I. Simonsen, B. Holst, Phys. Rev. Applied **11**, 024009 (2019).
[5] J. Fiedler, *et al.* in preparation.
[6] https://www.nanolace.eu/