On the similarities between micro/nano lithography and topology optimization projection methods

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The aim of the paper is to incorporate a model for micro/nano lithography production processes in topology optimization. The production process turns out to be physically analogous to using density projection filters in topology optimization. Usually, blue prints supplied by designers cannot directly be used as inputs to lithographic processes due to the proximity effect which causes rounding of sharp corners and geometric interaction of closely spaced design elements. However, due to above analogy, projection-based topology optimization can directly handle the proximity effect correction. Furthermore, it is demonstrated that the robust projection filter can be used to account for uncertainties due to lithographic production processes which results in manufacturable blueprint designs and eliminates the need for subsequent corrections.

Density projection schemes [1,2,3] have received increased popularity and are used to ensure discreteness of designs resulting from density based topology optimization schemes. Combined with the robust design approach [4], projection schemes may also ensure mesh-convergence and minimum feature size control of both solid and void phases. Hitherto, only the projected fields in these approaches have been associated with physical fields and the design variable field has only been considered as a mathematical entity. However, in this work we show that the design variable field can be interpreted directly as the dose pattern in electron-beam based micro- and nano-fabrication processes. The filtered density field corresponds to the local exposure which is blurred compared to the dose pattern due to scattering effects of the incoming electron beam. This observation leads to physical and mathematical insight and we further suggest modified optimization problems that ensure simplicity of the dose field and minimize manufacturing time [5].

In practical micro- and nano-processing proximity effects play an important role. Proximity effects entail that closely neighboring holes will etch differently compared to more distant holes with the same nominal size. Proximity effects are modeled by a double Gaussian weighting function for the density filter. Parameters for this function depend on manufacturing parameters, materials and layer thicknesses. We discuss and demonstrate the influence of using different materials for the design realizations.

[1] Guest J, Prevost J, Belytschko T (2004). Achieving minimum length scale in topology optimization using nodal design variables and projection functions. International Journal for Numerical Methods in Engineering 61(2):238–254.

[2] Sigmund O (2007). Morphology-based black and white filters for topology optimization. Structural and Multidisciplinary Optimization 33(4–5):401–424.

[3] Xu S, Cai Y, Cheng G (2010). Volume preserving nonlinear density filter based on Heaviside functions. Structural and Multidisciplinary Optimization 41:495–505.

[4] Wang F, Lazarov B, Sigmund O (2011). On projection methods, convergence and robust formulations in topology optimization. Structural and Multidisciplinary Optimization 43:767–784.

[5] Jansen, M.; Lazarov, B. S.; Schevenels, M. & Sigmund, O (2013). On the similarities between micro/nano lithography and topology optimization projection methods, *submitted.*