

Abstract - Dedicated Robotic Handling and Processing at the Submicrometer Scale: Feasibility Studies

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Robotic systems allowing for reliable operation at the submicrometer scale are becoming increasingly important for characterization and manipulation with nanometric precision. The most prominent representatives of these setups are scanning probe microscopes that have evolved into essential tools capable of various operation modes ranging from spectroscopy to the imaging and modification of single nanoentities. The growing demand for these capabilities is particularly caused by an ongoing trend towards miniaturization in various disciplines such as material science, life sciences, semiconductors, and micro- and nanotechnology.

However, to date, most scanning probe systems are restricted to the use of a single probe within a small working range, strictly limiting the application perspectives of these setups for increasingly complex robotic processing tasks at small scales. This work addresses the crucial issue mentioned above and focuses on dedicated robotic setups allowing for advanced robotic processing at the submicrometer scale. The developed setups function via the simultaneous and cooperative operation of different actors and tailored probes that are controlled through multiple sensing principles. Here, two concrete application scenarios are within the focus.

The first application scenario focuses on the robotic processing of graphene - a single atom-thick membrane of carbon atoms arranged in a honeycomb lattice. Here, a setup operating in ambient atmosphere is predominantly utilized. The setup allows for a variety of direct and fast processing techniques including optical detection and classification, mechanical and electrical characterization, targeted transfer, as well as modification of graphene via scanning probe lithography. Essential experimental results are cross-validated with Raman spectroscopy. Combining the capabilities of the platform allows for the rapid prototyping of graphene-based devices with nanoscale accuracy and without the need of any resist-based or wet-chemical processing steps. By these means, robotic processing techniques targeting graphene can effectively be studied and validated, which is an important condition for opening further application perspectives in research or even in industry.

The second application scenario addresses the robotic assembly of two- and three-dimensional structures consisting of individually stacked colloidal particles. Applying a dual-probe setup, integrated within a scanning electron microscope/focused ion beam unit, allows for reliable pick-up and release sequences of individual particles. The applied handling strategy is based on purposeful utilization of adhesive forces at the nanoscale through end effectors with an optimized geometry. In this way, even fully automated pick-and-place cycles are realized with hitherto unrivaled precision. The overall approach has been applied to prototypic fabrication of well-defined structures with nanoscale accuracy. Selected structures are specifically designed and fabricated for probing the near-field distribution of plasmonically excited nanoslits demonstrating unique advantages of the herein presented assembly approach.