[0005] Several emerging applications for GCIB processing of workpieces on an industrial scale exist for semiconductor/microelectronic device fabrication. At present, with continued dimensional scaling in advanced CMOS (complementary metal oxide semiconductor) logic, the requirements for dimensional variability control are concurrently increasing. For multiple technology nodes, advanced control using variable lithographic exposure across wafer has been used to help control critical dimensions in the plane of the wafer. Until the 22nm (nanometer) node, the most critical dimensions in the vertical dimension have been well controlled by a single deposition or oxidation step. However, with the implementation of replacement metal gate (RMG) techniques and FINFET (fin field effect transistor) structures, some critical dimensions, such as fin height and gate height, are affected by a combination of deposition, CMP (chemical mechanical planarization), and etch steps, requiring a new strategy for precision feature height control. Gas cluster ion beam (GCIB) technology offers precise correction of feature height non-uniformity using LSP algorithms.

[0006] Yet, in addition to correcting the non-uniformity present on the workpiece, the implementation of GCIB processing must also correct errors caused by system and/or equipment specific process anomalies that repeatedly affect the output process parameters of a GCIB apparatus. To improve LSP corrective capability, the systematic error for the GCIB processing system must be determined using sacrificial workpieces, which is costly and time intensive.

SUMMARY OF THE INVENTION

[0006a] According to a first aspect of the present invention, there is provided a method of modifying an upper layer of a workpiece using a gas cluster ion beam (GCIB), the method comprising: collecting parametric data relating to an upper layer of a workpiece, said parametric data including an initial profile of a measured attribute of said upper layer and at least one n^{th} order derivative of a spatial variation of said measured attribute, wherein n is an integer greater than zero; determining a predicted systematic error response for applying a GCIB to said upper layer to alter said initial profile of said measured attribute by using said parametric data, including said at least one n^{th} order derivative, as input to a pre-established, predictive model; identifying a target profile of said measured attribute; directing a gas cluster ion beam (GCIB) toward said upper layer of said workpiece; and spatially modulating an applied property of said GCIB, based at least in part on said predicted systematic error response and said

parametric data, as a function of position on said upper layer of said workpiece to achieve said target profile of said measured attribute.

[0006b] According to a second aspect of the present invention, there is provided a processing system configured to perform location specific processing on a workpiece, comprising: a GCIB processing system configured to treat a workpiece with a GCIB; and a multi-process controller configured to: receive parametric data relating to an upper layer of a workpiece, said parametric data including an initial profile of a measured attribute of said upper layer and at least one n^{th} order derivative of a spatial variation of said measured attribute, wherein n is an integer greater than zero; determine a predicted systematic error response for applying said GCIB to said upper layer to alter said initial profile of said measured attribute by using said parametric data, including said at least one n^{th} order derivative, as input to a pre-established, predictive model; identify a target profile of said measured attribute; direct said GCIB toward said upper layer of said workpiece; and spatially modulate an applied property of said GCIB, based at least in part on said predicted systematic error response and said parametric data, of said GCIB as a function of position on said upper layer of said workpiece to achieve said target profile of said measured attribute.

[0007] Embodiments of the invention relate generally to the fields of material processing and semiconductor integrated circuit manufacturing and, more specifically but not exclusively, relate to correction of systematic errors or non-uniformities through location specific processing using gas cluster ion beam (GCIB) technology. In particular, a predictive method is used to accommodate for systematic error when performing GCIB location specific processing.

[0008] According to one embodiment, a method of modifying an upper layer of a workpiece using a gas cluster ion beam (GCIB) is described. The method includes collecting parametric data relating to an upper layer of a workpiece, and determining a predicted systematic error response for applying a GCIB to the upper layer to alter an initial profile of a measured attribute by using the parametric data. Additionally, the method includes identifying a target profile of the measured attribute, directing the