METHODOLOGY BETWEEN THEORETICAL MODELING AND EXPERIMENTAL TRIALS FOR DEPTH FILTER MEDIA OF MICRO/NANO PARTICLES IN SLURRY

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INTRODUCTION

Chemical mechanical planarization (CMP) is a critical process in advanced and mature nodes of semiconductor manufacturing. For CMP process, filtration is the turnkey of defectivity reduction in driving force. So, know the fundamental of filtration is important to optimize CMP. This study presents the results of comparing large particle retention studies and indirect analysis for small particles to simulations during filtration. 3D depth media structure with real physical properties were successfully established to improve simulation accuracy.

BACKGROUND

CMP is an essential unit process in advanced semiconductor industry. Lower large particle count (LPC) can reduce scratches, particularly by employing slurry filtration. LPC retention efficiency is determined by the filter media materials and slurry abrasives used during CMP [1]. Nowadays, microfiltration and nanofiltration techniques in liquid region, referred to as filter media with pore sizes below 1 um and below 100 nm, respectively, are being widely used in semiconductor and general industries. In the following, important aspects of liquid filtration of large particles (>0.5um) and small nanoparticles (<50nm) will be discussed to ensure a common understanding of the stated problem and the important influencing factors. These include particle transport, particle-particle as well as particle-depth media interactions together with the role of the continuous phase. Therefore, comparing theoretical and empirical results of filtration performance is essential for CMP.

EXPERIMENTAL

The colloidal Ceria abrasives to filtration media with multiple components is used for experimental and simulation with 200 nm mean particle size, <0.1 wt% and neutral. The particle distribution is shown in (Fig. a). The applied conditions such as the working environment is at 25^{o}C, 1 atm and the volumetric flowrate is 0.25 LPM.

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In this research, the basic filtration testing includes single pass testing and circulation testing as below, Prepare the target filtrate slurry with de-ionized (DI) water diluted, pH and additive adjustment. Analyze the properties of target fabric depth media such as 3D media structure, zeta potential of media and surface energy of media and so on. Install target depth media on filtration test stand. There are two testing loops as below in (Fig. 1b). Circulation filtration loop: apply lower flow rate (0.25 LPM) marked by solid line for mimicking end user's application of semiconductor. Flush target depth media by DI water on specific filtration loop with flow rate 0.35 LPM for circulation filtration, then flush the media by the target slurry with flow rate 0.25 LPM for single pass filtration. Then, keep slurry flow pass through media with specific flow rate during 1 minute for flow stability. After that, start to collect the filtrated sample of upstream and downstream. Finally, start to measure the filtration performance of the filtrated samples of upstream and downstream by off-line testing.

After completed filtration experiment in test stand, analyze the properties of un-filtrated (upstream) and filtrated (downstream) slurry such as particle size distribution, zeta potential, surface energy, solid content, filtration retention from particle counting of upstream/downstream and so on. The retention definition is filtrated particle counts divided by initial filtrate particle counts. During filtration, can also collect pressure drop trend to calculate filter lifetime.

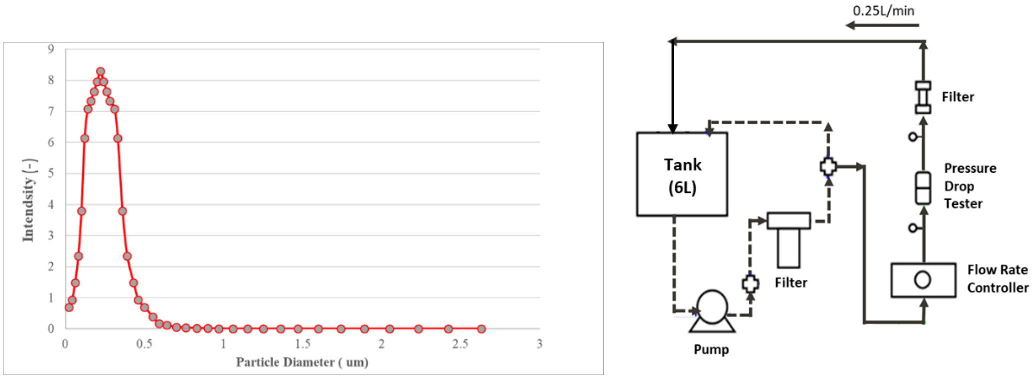

Fig. 1 (a) Particle size distribution of ceria abrasives. (b) Circulation filtration loop in test stand.

On the other hand, the set of simulations was performed with the software. This program is a voxel-based code dedicated to predicting material properties by solving transport equations for a virtual material. The mesh is formed of voxels, which can be empty (fluid) or filled (solid). The simulation is separated into two parts, which are flow field simulation and particles tracking simulation.

Explicit finite volume solver options are controlled with the flow module. The liquid flow through the microstructure is governed by the Navier-Stokes equations, which consist of the momentum balance equation:

$$-\mu\Delta\boldsymbol{u} + (\rho\boldsymbol{u}\cdot\nabla)\boldsymbol{u} + \nabla p = \vec{f} \qquad (1)$$

and the continuity equation:

$$\nabla\cdot\boldsymbol{u} = 0 \qquad (2)$$

where $\boldsymbol{u}$ is the velocity vector and u, v and w are its components along the x, y and z directions respectively. p is the pressure and μ is the dynamic viscosity. Velocity inlet and pressure outlet boundary conditions are used in the flow direction. Permeability was chosen as the stopping criterion. In each iteration, permeability is calculated from the current flow field using Darcy's law.

The simulation of filter efficiency and lifetime in filter media is designed as multi pass filtration process. Besides, test dust (in g), the pump flow rate (in l/min), and the test filter area (in cm^2), here the injection reservoir volume and the test reservoir volume (recirculation) can be entered. The outflow to upstream sampler and the outflow to downstream sampler (in ml/min) can also be set. The injection flow rate matches the sum of the upstream and the downstream outflows (in ml/min). As default, the multi-pass test is set up according to the ISO standard (Multi Pass Test [ISO 16889] Standard).

DISCUSSION

In this study, we established theoretical models coupled with experimental trials to describe filter performance in slurry. The actual and simulated results of the combination of retention, and visual methodology were separately examined.

From the beginning of filtration in circulation, much higher volumes of ceria particles are caught by specific media component. Turnover means 1 run with test slurry tank from top to bottom by T. As turnovers go by, lower and lower volume of ceria particles are caught. That also means less and less large particles are caught during filtration. Because most of these particles are caught in beginning (Fig. 2a).

In the next, much higher volume of ceria particles are caught by the other component in media following. As turnovers go by, lower and lower volume of ceria particles are caught. That also means less and less large particles are caught during filtration. Because most of these particles are caught in beginning. Compared to previous material component, most of the particles gradually removed. Then, the remain just can be caught (Fig. 2b).

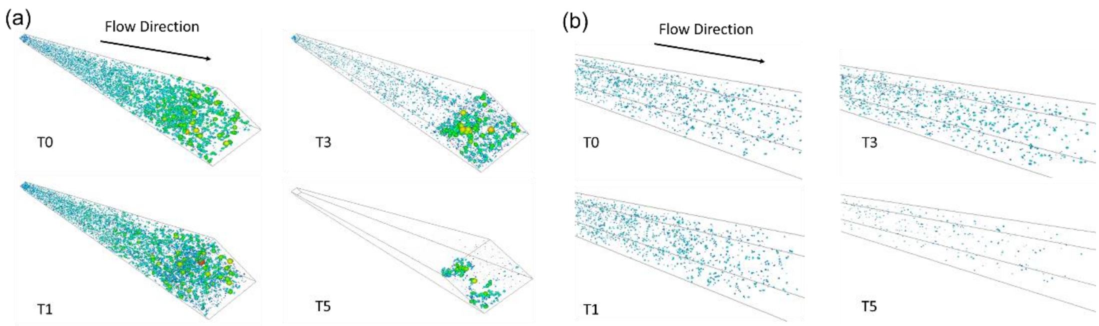

Fig. 2 (a) Particle catching during circulation filtration with component in media. (b) Particle catching during circulation filtration gradually following.

In summary, transfer 3D modeling data to final prediction value to compare experimental data by retention. Depth media filters with retention ratings ≥0.3 µm were tested for retention, and the results compared favorably to simulations (Fig. 3a). However, small particles are more difficult to model. Particles smaller than 0.1 µm tend to be captured by Van der Waals and electrostatic forces (Fig. 3b) and require different methodologies for empirical testing to indirectly analyze the results. With the assistance of cross-section analysis, we found that captured particles were mainly located at the interface of different materials.

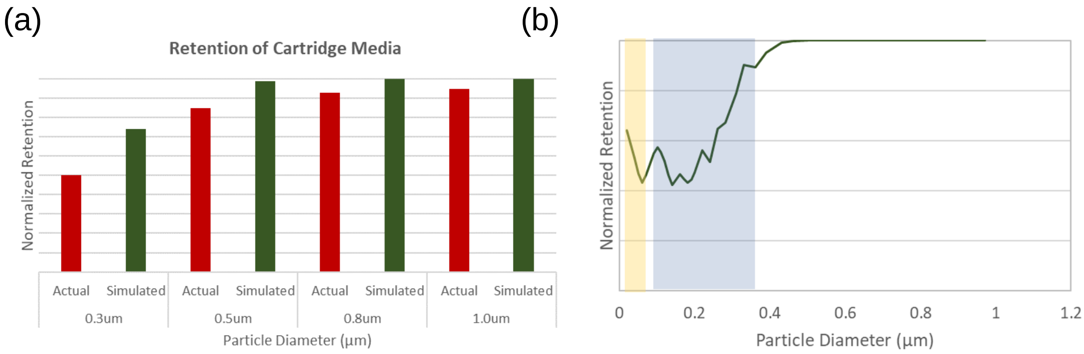

Fig. 3 (a) Comparison of actual and simulated retention results for filtration media with ≥0.3 µm ratings. (b) Filter efficiency simulation, combining retention mechanisms.

CONCLUSIONS

This study presents the results of comparing large particle retention studies and indirect analysis for small particles to simulations. 3D depth media structure with real physical properties were successfully established to improve simulation accuracy in validation between modeling and experiment. In the future, this methodology is one of effective ways to screen filtrated slurry performance in CMP application.

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