END-POINT PROCESS DEVELOPMENT FOR LOW-VOLUME, HIGH RELIABILITY TUNGSTEN CMP

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Executive Summary

A temperature end-point method was developed for tungsten CMP (WCMP) processing in the Sandia Microelectronics Development Laboratory (MDL), a facility which develops and prototypes a variety of silicon-based devices including ASIC, memory, radiation-hardened CMOS and microelectromechanical systems. A large product variety and small production lot size prevents process recipe optimization or standardization for each mask level and product. Rigorous product reliability requirements and prohibitively expensive hardware qualifications essentially require that a single process and consumable set be established for all products, with minimal opportunity for adjustment. A timed process was not suitable without significant potential for manual inspections and rework. Over several weeks of processing on an IPEC 472, the temperature end-point method gave a 7.7% 1-sigma end-point time distribution. This enabled a 50% reduction in daily process qualification wafers, and allowed minimization of yield loss, rework, and oxide erosion.

Extended Abstract

Low-volume, high-reliability manufacturing is a critical nuclear weapons capability for the Department of Energy. Smaller production lot sizes, a wider variety of products, and intermittent rather than continuous manufacturing are typical characteristics of this manufacturing regime. In such a production environment, the determination of process end-point for WCMP is required to achieve complete metal removal and eliminate polish rework. Proper end-point identification is critical to reducing defects and dielectric thinning associated with overpolish, as well as minimizing processing cost (1). End-point may be found by calculating a fixed polish time based

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on per-shift monitor wafer rates, by monitoring pad-wafer friction via motor current to the polishing head, or by other sensing technologies (2). Complete reliance upon a timed process for WCMP of a single product interconnect level is most suitable where the expected variability in process consumables and incoming product is minimal or may be frequently and inexpensively characterized. With proper configuration, a timed process has a low risk for rework due to incomplete polish, but requires a longer, conservative overpolish and predictable consumables performance. In contrast, reliance upon sensor-based methods for process automation demands reliable instrumentation and a robust technique that is insensitive to consumables variability. For a given interconnect level, both the timing and sensor methods should be developed with a sufficient number of product wafers to account for statistical variability in consumables performance, film thickness variation, pattern layout effects, and prior dielectric CMP performance. The worst-case scenario for WCMP process automation exists when installed polishing pad condition varies substantially, few product and monitor wafers are available for process development, and a wide variety of products are manufactured. Thus, an end-point method for the MDL's baseline WCMP process was developed for the IPEC 472, using the built-in pad temperature sensor as instrumentation. The baseline CMP process has been described elsewhere in detail (3). The optimized end-point method is performed as follows: with primary platen temperature set to 110 °F, polish at 7-9 psi while conditioning, and stop conditioning prior to exposure of Ti/TiN film. Monitor primary pad temperature as it initially increases and then stabilizes during W removal. As the W film begins to clear and Ti/TiN liner film is exposed, pad temperature will first gradually and then sharply increase several degrees to a peak temperature for a few seconds, then decline rapidly. From the time at which the pad temperature has fallen 4 °F from its peak, begin a timed overpolish to clear the remaining liner film. (Additional details of this procedure are not included here for space limitations; please see poster presentation.) This method has been evaluated for three different slurry oxidizer chemistries on a Rodel IC 1400 K-groove polishing pad. For via fill, tungsten was deposited by CVD in a Genus 8720 system onto a liner consisting of 200Å Ti capped by 500Å TiN, and liner deposition was preceded by a 75Å sputter etch (4). After initial studies on blanket W monitors, this method was characterized through passive data collection over several weeks of production polishing. Concurrently, an end-point method based on wafer-pad friction as sensed by carrier motor current was studied, but was not found to be robust. The failure of the carrier current method seemed to arise from variability in pad age and condition upon demand, despite aggressive pad preconditioning, causing a high day-to-day variability in WCMP rate for daily monitor wafers (Table I). Due to varying production demand, the polishing pad and insert could sit idle and wet for several days between production runs, and pads could not be feasibly be replaced for every day's production (typically up to 24 product wafers, plus 6 monitors per day, reduced later to 3 daily monitors). Monitor rate variability was also due to a failure to reach steady state in polishing pad surface conditions in the economically brief rate qualification process. A two-component slurry was mixed as needed in small batches (~5 gallons). As shown in Table I and Figure I, the end-point method is reproducible and robust, with the distribution of end-point times showing only a 1.8% 1-sigma increase in WTW nonuniformity, accounting for all variation attributable to tool, operator, slurry, pad state, previous ILD planarization, and layout.

TABLE I. Pad Temperature End-point Method Performance

Process metric	Mean	Nonuniformity, % 1-sigma
Incoming W monitor thickness	8360 Å (n = 168)	5.9 % WTW
Polish time, nominal 8kÅ deposition on product wafers	217 seconds (n = 194) 23 lots over 7 products	7.7 % WTW
Pad peak temperature for nominal 8kÅ product wafers	129 °F	5.2 % WTW
Daily monitor W CMP rate	3400 Å/min (n = 14)	9.3% (day to day)
Polish time, nominal 10kÅ deposition on product wafers	235 seconds (n = 55) 8 lots over 3 products	5.7 % WTW
Pad peak temperature for nominal 10kÅ product wafers	131 °F	3.6 % WTW

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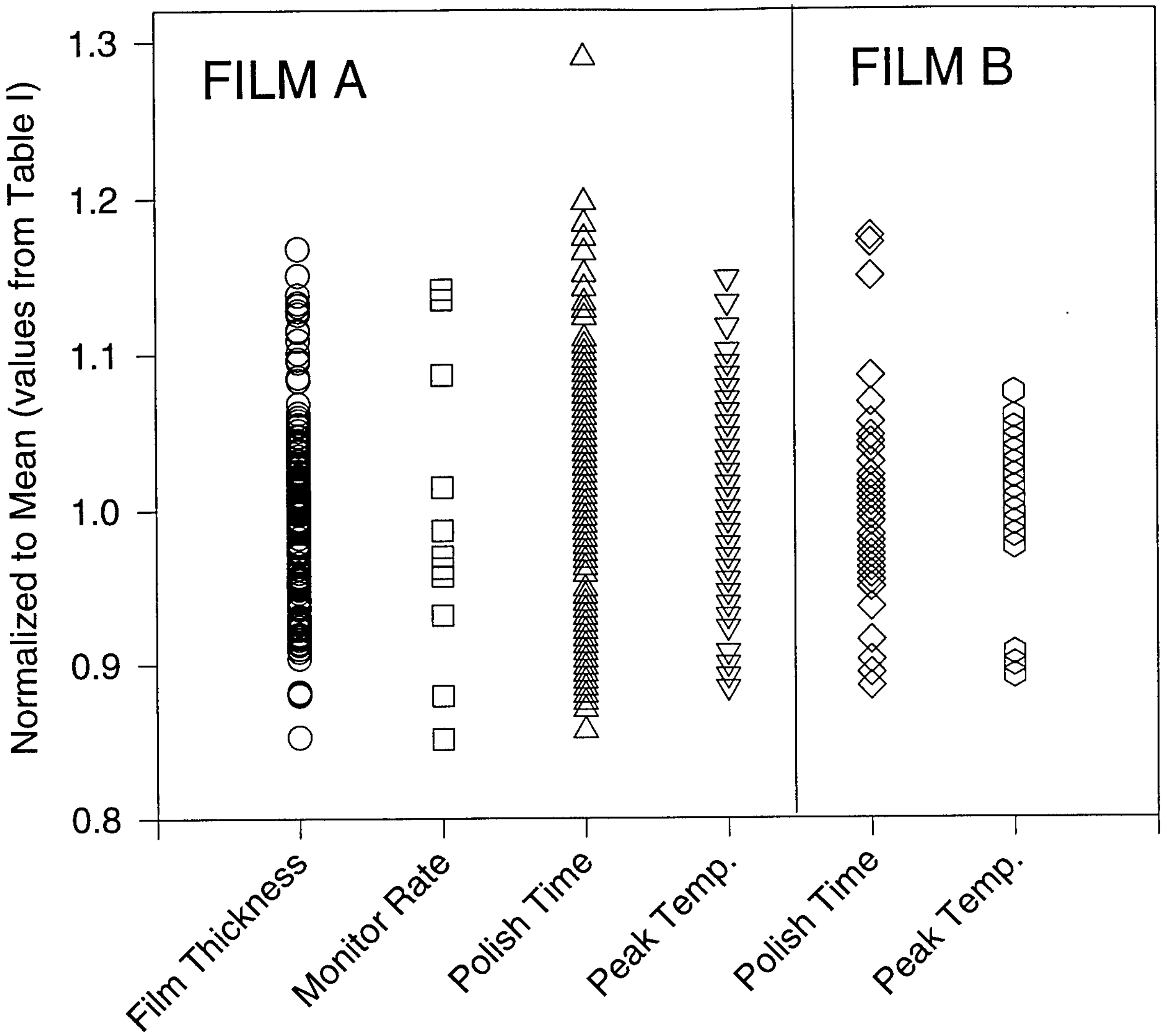

FIGURE 1. Film A = 0.8 micron nominal W. Film B = 1 micron nominal W.

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