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A Closed-Loop Temperature Control System for a Low-Temperature Etch Chuck

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ABSTRACT

A closed-loop temperature control system has been developed for use in a low-temperature (-135°C) plasma etch system. The system employs an optical fluorescence probe on the chuck (a second probe monitors the wafer temperature as well) to provide feedback to the heating element on the input line of the chuck closed-loop coolant fluid. A simple proportional-integral-derivative (PID) controller with a learn mode controls the rate of current pulses applied to the heater. Innovations include the direct measurement of chuck temperature for the control signal, and the coupling of large cooling and heating capacities in close proximity to the chuck along with a fast fluid flow to guarantee quick response.

The system has been tested in prolonged etch runs of many wafers. It provides reliable, tight temperature control (3σ as low as 0.6°C). This level of control is significantly tighter than could be achieved by merely monitoring chiller bath temperatures.

1. INTRODUCTION

As semiconductor features become smaller and process requirements become stricter, advanced plasma etch systems require tighter control over their process factors. A recent project at SEMATECH worked to develop an etch system that would provide tight control of wafer temperature for low-temperature etch applications.

This paper discusses the hardware for both the sensors and control systems, as well as results of the temperature stability, over various extended runs of hundreds of wafers.

2. SUPPORTING HARDWARE

2.1 Fiber optic temperature probe

The fluoroptic thermometric technique developed by Luxtron uses the photoluminescent response of a magnesium fluorogermanate phosphor to blue light pulses transmitted down a fiber optic cable probe. The rate of decay of the fluorescence is measured and correlated to temperature. Two types of fluoroptic

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probes are available. The first type ("remote" or non-contacting) uses a phosphor dye painted on the sample and receives the data into the fiber from a distance. The second type ("contact") uses the phosphor in an encapsulation at the end of the fiber. Surrounded by a protective coating, this probe is used to make physical and thermal contact with the sample. For the application investigated during the project, either type could have been used for the electrode probe. The etch system used in the project had two chambers, each with separate "contact" probes for monitoring electrode temperature and wafer temperature.

The electrode temperature was monitored to determine the stability of the cooling system. The wafer temperature was used to determine the interaction of the etch process and the cooling system.

2.2 Chiller systems

Two different cooling systems were used in the tool. For the -70°C chamber, a standard bath-type chiller was chosen. This style of chiller controls the temperature of a bath through which a heat transfer fluid circulates on its way to the electrode (some 5 to 10 meters away).

For the -135°C chamber, a system from Polycold was chosen. This cryo-cooler was unique in two ways. First, the refrigerant (a mixture of Freons and argon) was circulated through the electrode. This afforded a higher heat removal efficiency than circulating a heat transfer fluid between a refrigerated bath and the electrode. Second, there was no built-in feedback system for temperature control. These systems are normally run at "maximum output" for high-vacuum cold-trap applications, with the temperature controlled by the composition of the refrigerant mixture. This made it necessary to add a separate system for controlling the electrode temperature.

3. HEATER/CONTROLLER DESIGN

The throttling approach to temperature control consisted of a valved coolant path that bypassed the chuck, allowing some of the cooling fluid to be diverted away from the chuck in order to lower the effective cooling power of the Polycold system. This approach failed for three main reasons:

- Large valves that work reliably at -150°C are prohibitively expensive.
- The chuck cooling capacity was lowered (since most of the coolant would be bypassed).
- The two-phase nature of the refrigerant meant different mixtures of constituents flowed in the main and bypass lines, also lowering cooling efficiency.

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