

CLAIMS

1. In a plasma chamber for processing a semiconductor wafer, circuitry for monitoring and adjusting a pulsed RF bias voltage signal to be applied to a chuck in the plasma chamber, the chuck being configured to mount the wafer for processing, the circuitry comprising:
 - an RF bias voltage detector for detecting individual pulses of the pulsed RF bias voltage signal applied to the chuck;
 - a timing circuit for determining a time for sampling each of the individual detected pulses;
 - a sample and hold circuit triggered at the sampling time for sampling each of the individual detected pulses to determine and hold a voltage value representing a characteristic peak-to-peak voltage value of each individual detected pulse, wherein the sample and hold circuit is configured to provide a feedback signal representing the characteristic peak-to-peak voltage value of at least one of the detected pulses; and
 - a feedback circuit for adjusting the voltage of the pulsed RF bias voltage signal applied to the chuck according to a difference between the feedback signal and a desired voltage value of the RF bias voltage signal.
2. Circuitry as recited in claim 1, wherein the RF bias voltage detector is configured to detect each individual pulse of the pulsed RF bias and output a voltage envelope representing peak-to-peak voltage values within each individual detected pulse.
3. Circuitry as recited in claim 2, wherein the timing circuit is configured to detect a rising edge of each of the individual detected pulses and to determine the sampling time delayed from the rising edge so that the sample and hold circuit triggered at the sampling time samples the voltage envelope to determine the voltage value representing the characteristic peak-to-peak voltage value of each individual pulses.
4. Circuitry as recited in claim 1, wherein the sample and hold circuit is configured to detected pulses to determine and hold a voltage value representing one or more peak-to-peak

voltage values of an envelope of each individual detected pulse, the one or more peak-to-peak voltages values including the average or maximum peak-to-peak voltage value within a pulse.

5. Circuitry as recited in claim 1, wherein the sample and hold circuit is configured to average a plurality of the determined held voltage values.

6. A method of monitoring and adjusting a pulsed RF bias voltage signal to be applied to a chuck in a plasma chamber for processing a semiconductor wafer, the chuck being configured to mount the wafer for processing, the method comprising the operations of:

detecting voltage values of individual pulses of the pulsed RF bias voltage applied to the chuck;

determining a time at which to sample a voltage value of each of the individual detected pulses;

at the sampling time with respect to each of the individual detected pulses sampling a particular voltage value of the respective individual detected pulse and holding the particular voltage value, each respective particular voltage value representing at least a characteristic peak-to-peak voltage value of each respective individual detected pulse;

generating a feedback signal representing at least the characteristic peak-to-peak voltage value for a voltage envelope of one of the individual detected pulses; and

adjusting the voltage of the pulsed RF bias voltage signal applied to the chuck according to a difference between the feedback signal and a desired voltage value of the pulsed RF bias voltage signal.

7. A method as recited in claim 6, wherein the detecting operation provides the voltage envelope representing peak-to-peak voltage values of each individual pulse of the respective pulses of the pulsed RF bias voltage signal.

8. A method as recited in claim 6, wherein the determining operation identifies a sampling time or multiple sampling times temporally spaced from a rising edge of each of the detected individual pulses so that each sampled particular voltage value of a respective individual detected pulse or the characteristic function that is an average of multiple samples within an

individual detected pulse represents a characteristic peak-to-peak voltage value of the respective individual detected pulse.

9. A method as recited in claim 6, wherein averaging is performed for two or more peak peak-to-peak voltage values of the respective individual detected pulses.

10. Apparatus for measuring a pulsed RF bias signal applied to a bias electrode of a wafer processing chamber; the apparatus comprising:

a detector configured for response to the pulsed RF bias signal, the pulsed RF bias signal comprising of a pair of ON mode pulses separated by an OFF mode, the detector being configured to generate a detector signal comprising successive envelopes, amplitudes of a respective one of the envelopes being proportional to peak-to-peak voltage values as a function of time of a respective ON mode pulse; and

a sample and hold circuit for sampling each successive one of the envelopes, the sampling identifying one of the amplitudes of the envelope, the identified one amplitude representing the characteristic peak-to-peak voltage value of the respective ON mode pulse corresponding to the envelope, the circuit generating an output signal in proportion to the identified one amplitude.

11. Apparatus as recited in claim 10, the apparatus further comprising a timing circuit configured to generate a trigger signal for triggering the sample and hold circuit on completion of a delay following a rise period of each of the envelopes so that each identified one amplitude represents the characteristic of the peak-to-peak voltage values of the ON mode pulse corresponding to the respective envelope.

12. Apparatus as recited in claim 11, wherein:

the apparatus is also configured to measure a CW RF bias signal; and

the timing circuit is further configured with a watchdog circuit effective to generate the trigger signal upon generation of the CW RF bias signal in lieu of the pulsed RF bias signal.

13. Apparatus as recited in claim 10, further comprising:
an averaging circuit configured to add the identified one amplitudes sampled from a preset number of the respective successive envelopes to obtain a sum and to divide the sum by the preset number to generate the output signal having a value in proportion to an average of the characteristic peak-to-peak voltage values of the ON mode pulses corresponding to the respective preset number of envelopes.
14. Apparatus as recited in claim 13, wherein:
the preset number is selected according to an update frequency at which the output signal is to be updated; and
the averaging circuit is configured to update the output signal at the update frequency, the values of the output signal being independent of a duration of the OFF modes.
15. Apparatus as recited in claim 13, wherein:
the averaging circuit is further configured based on selecting the preset number according to the durations of the ON and OFF modes and according to an update frequency at which the output signal is to be updated.
16. Apparatus as recited in claim 10, wherein:
the sample and hold circuit is configured to sample envelope amplitudes having voltage values less than a voltage limit;
the peak-to-peak voltage values of the ON mode pulses exceed the voltage limit;
and
the detector is configured with a plurality of stages, each of the stages is configured to attenuate the voltage values of the ON mode pulses so that the voltage values of the amplitudes of the envelopes are less than the voltage limit.
17. Apparatus as recited in claim 10, wherein:
each ON mode pulse consists of RF cycles; and

the detector comprises a circuit configured with a storage device and a diode network, the diode network enabling the storage device to store for each cycle a value representing the peak-to-peak voltage of the cycle.

18. Apparatus as recited in claim 10, wherein:

the pulsed RF bias signal comprises RF cycles;

the detector comprises a peak-to-peak detector circuit;

the detector circuit is configured with a pair of oppositely conducting diodes and a capacitor for storing a charge proportional to the peak-to-peak voltage values of the cycles of the ON mode pulses of the pulsed RF bias signal;

each of the diodes is configured with a capacity to conduct current up to a current limit; and

the detector further comprises a separate circuit in series with each of the diodes, the separate circuits are configured so that each of the diodes conducts current up to the current limit as the capacitor is charged.

19. Apparatus for measuring a pulsed RF bias signal applied to a bias electrode of a wafer processing chamber, the apparatus comprising:

a detector configured for response to the pulsed RF bias signal, the pulsed RF bias signal consisting of pairs of ON mode pulses, each pair being separated by an OFF mode, each ON mode pulse consisting of cycles, each cycle being characterized by a voltage amplitude that varies with respect to time, the detector being configured so that the response is generating a detector signal in the form of successive envelopes, amplitudes of one of the envelopes consisting of amplitude values that are proportional to peak-to-peak voltage values of the cycles of a respective one of the ON mode pulses, the amplitudes of a respective envelope being with respect to time only during a respective ON mode pulse, each envelope being independent of a duty cycle and of a frequency of the pulsed RF bias signal; and

a sample and hold circuit configured for operation with respect to each of successive ones of the spaced envelopes, the sample and hold circuit sampling an envelope amplitude having an amplitude value proportional to a characteristic peak-to-peak voltage value of the

cycles of the respective ON mode pulse and holding the sampled amplitude value until sampling of a next envelope, the sample and hold circuit generating an output signal having a value proportional to the characteristic peak-to-peak voltage value of the cycles of the respective ON mode pulse.

20. Apparatus as recited in claim 19, the apparatus further comprising a timing circuit configured to generate a trigger signal for triggering the sample and hold circuit on completion of a rise period and of a transition period of each of the respective envelopes.

21. Apparatus as recited in claim 19, wherein the sample and hold circuit is configured with:

a sampling module that samples a plurality of successive values of the amplitude of the respective envelope; and

a selecting module that determines which of the plurality of sampled amplitude values is proportional to the characteristic peak-to-peak voltage value of the cycles of the respective ON mode pulse.

22. Apparatus as recited in claim 21, wherein the selecting module is configured:

to make the determination with respect to two sampled amplitude values of the peak-to-peak voltage value of the cycles of the respective ON mode pulse and to hold the higher value sample;

to make the determination with respect to the held higher value sample and a sample of the next successive amplitude value of the cycles of the respective ON mode pulse and to hold the higher value sample; and

to stop making the determinations when the sample of the next successive amplitude value is less than the higher value of the held sample and to hold the higher value held sample for use in generating the output signal having a value in proportion to the characteristic peak-to-peak voltage value of the cycles of the respective ON mode pulse.

23. Apparatus as recited in claim 19, wherein for each of the respective successive envelopes the sample and hold circuit samples a characteristic envelope amplitude value proportional to a characteristic peak-to-peak voltage value of the cycles of the respective ON mode pulse to which the respective successive envelope corresponds; and the apparatus further comprises an averaging circuit configured to obtain a sum by adding the characteristic amplitude values of a preset number of the respective successive envelopes, wherein the preset number is selected so that an update time period during which the output signal is updated equals the number of successive envelopes divided by a pulse rate of the pulsed RF bias signal, the averaging circuit being further configured to divide the sum by the preset number to generate the output signal having a value that is proportional to an average of the characteristic peak-to-peak voltage values of the cycles the ON mode pulses that correspond to the preset number of respective successive envelopes.

24. Apparatus for measuring voltage values of a pulsed RF bias signal applied to a bias electrode of a wafer processing chamber, the signal consisting of an ON mode pulse followed by an OFF mode followed by another ON mode pulse and continuing in a series of alternating ON mode pulses and OFF modes, a pulse rate defining times at which successive ones of the ON pulses start, each ON mode pulse consisting of cycles, each cycle being characterized by voltage values that vary with respect to time and that include a peak-to-peak voltage value of the cycle, the apparatus comprising:

a detector configured for response to each ON mode pulse of the continuing series for generating a detector signal in the form of one envelope corresponding to each of the ON mode pulses and spaced from other successive envelopes according to the pulse rate, each envelope representing peak-to-peak voltage values of the cycles of a respective one of the ON mode pulses, the detector being configured so that the detector signal consists of one envelope followed by a successive one OFF mode followed by one envelope in a continuing series of OFF modes and envelopes alternating at the pulse rate; and

a sample and hold circuit configured to be triggered for operation only with respect to each successive one of the envelopes, the triggered circuit sampling a voltage amplitude value of a respective envelope and holding the sampled value during the next OFF mode, the held

sampled value representing the characteristic peak-to-peak voltage value of the cycles of the ON mode pulse corresponding to the respective envelope.

25. Apparatus as recited in claim 24, further comprising:

a feedback circuit for controlling the voltage values of the pulsed RF bias signal applied to the bias electrode, the feedback circuit generating a control signal at an update rate, the update rate being slower than the pulse rate and defining a time period between updates of the control signal.

26. Apparatus as recited in claim 25, further comprising:

an averaging circuit responsive to a number of the held voltage amplitude values representing the characteristic peak-to-peak voltage values of the cycles of respective successive ON mode pulses corresponding to respective envelopes occurring in succession during one of the update time periods, the averaging circuit generating an average of the held voltage amplitude values to represent an average of the characteristic peak-to-peak voltages values of the ON mode pulses during the one update period; and

the feedback circuit updating the control signal in response to the average of the held voltage amplitude values.

27. Apparatus as recited in claim 26, wherein the averaging circuit obtains a sum of the held voltage amplitude values held during the one update time period and divides the sum by the number of the held voltage amplitude values to determine the average.

28. A method of determining a peak-to-peak voltage value of a pulsed RF bias signal applied to an RF bias electrode supporting a substrate in a processing chamber, the applied signal consisting of alternating modes, the modes consisting of an ON mode pulse and an OFF mode and an ON mode pulse that continue in a series of modes, the method comprising the operations of:

identifying a first ON mode pulse of the pulsed RF bias signal, the first ON mode pulse being characterized by amplitudes of cycles that vary with respect to time;

defining an envelope representing peak-to-peak voltage values of the amplitudes of the cycles of the identified first ON mode pulse as a function of time during the first ON mode pulse; and

sampling the envelope to generate an output signal representing the characteristic peak-to-peak voltage value of the pulsed RF bias signal.

29. A method as recited in claim 28, the method comprising the further operation of: generating a feedback signal for controlling the voltage value of the pulsed RF bias signal, the feedback signal being based on the characteristic peak-to-peak voltage value of the output signal and on a desired peak-to-peak voltage value of the pulsed RF bias signal.

30. A method as recited in claim 28, comprising the further operations of: repeating the identifying, defining, and sampling operations with respect to successive ON modes pulses of the series to update the output signal based on the envelopes representing peak-to-peak voltage values of the amplitudes of the cycles of the successive ON mode pulses.

What is claimed is:

1. In a plasma chamber for processing a semiconductor wafer, circuitry for monitoring and adjusting a pulsed RF bias voltage signal to be applied to a chuck in the plasma chamber, the chuck being configured to mount the wafer for processing, the circuitry comprising:

an RF bias voltage detector for detecting individual pulses of the pulsed RF bias voltage signal applied to the chuck;

a timing circuit for determining a time for sampling each of the individual detected pulses, wherein the time for sampling corresponds to a time when a characteristic peak-to-peak voltage value occurs in each individual detected pulse, the characteristic peak-to-peak voltage representing a maximum peak-to-peak voltage of an envelope of each individual detected pulse;

a sample and hold circuit triggered at the sampling time for sampling each of the individual detected pulses to determine and hold a voltage value representing the characteristic peak-to-peak voltage value of each individual detected pulse, wherein the sample and hold circuit is configured to provide a feedback signal based on the characteristic peak-to-peak voltage value of at least one of the detected pulses; and

a feedback circuit for adjusting the voltage of the pulsed RF bias voltage signal applied to the chuck according to a difference between the feedback signal and a desired voltage value of the RF bias voltage signal to hold electrical characteristics of the plasma steady during processing to compensate for a variation of an impedance presented to the chuck.

2. Circuitry as recited in claim 1, wherein the RF bias voltage detector is configured to detect each individual pulse of the pulsed RF bias and output the voltage envelope representing peak-to-peak voltage values within each individual detected pulse.

3. Circuitry as recited in claim 2, wherein the timing circuit is configured to detect a rising edge of each of the individual detected pulses and to determine the sampling time delayed from the rising edge so that the sample and hold circuit triggered at the sampling time samples the voltage envelope to determine the voltage value representing the characteristic peak-to-peak voltage value of each individual pulse.

4. Circuitry as recited in claim 1, wherein the sample and hold circuit is configured to detected pulses to determine and hold a voltage value representing one or more peak-to-peak voltage values of the envelope of each individual detected pulse.

5. Circuitry as recited in claim 1, wherein the sample and hold circuit is configured to average a plurality of the determined held voltage values.

6. Apparatus for measuring a pulsed RF bias signal applied to a bias electrode of a wafer processing chamber, the apparatus comprising:

a detector configured for response to the pulsed RF bias signal, the pulsed RF bias signal comprising of a pair of ON mode pulses separated by an OFF mode, the detector being configured to generate a detector signal comprising successive envelopes, amplitudes of a respective one of the envelopes being proportional to peak-to-peak voltage values as a function of time of a respective ON mode pulse; and

a sample and hold circuit for sampling each successive one of the envelopes at a sampling time when a characteristic peak-to-peak voltage value occurs in each envelope, the characteristic peak-to-peak voltage representing a maximum peak-to-peak voltage of the envelope of each individual detected pulse, the sampling identifying one of the amplitudes of the envelope, the identified one amplitude representing the characteristic peak-to-peak voltage value of the respective ON mode pulse corresponding to the

envelope, the sample and hold circuit generating an output signal in proportion to the identified one amplitude, the output signal being used for holding electrical characteristics of a plasma steady during processing to compensate for a variation of an impedance presented to the electrode.

7. Apparatus as recited in claim 6, the apparatus further comprising a timing circuit configured to generate a trigger signal for triggering the sample and hold circuit on completion of a delay following a rise period of each of the envelopes so that each identified one amplitude represents the characteristic of the peak-to-peak voltage values of the ON mode pulse corresponding to the respective envelope.

8. Apparatus as recited in claim 6, further comprising:

an averaging circuit configured to add the identified one amplitudes sampled from a preset number of the respective successive envelopes to obtain a sum and to divide the sum by the preset number to generate the output signal having a value in proportion to an average of the characteristic peak-to-peak voltage values of the ON mode pulses corresponding to the respective preset number of envelopes.

9. Apparatus as recited in claim 8, wherein:

the preset number is selected according to an update frequency at which the output signal is to be updated; and

the averaging circuit is configured to update the output signal at the update frequency, the values of the output signal being independent of a duration of the OFF modes.

10. Apparatus as recited in claim 8, wherein:

the averaging circuit is further configured based on selecting the preset number according to the durations of the ON and OFF modes and according to an update frequency at which the output signal is to be updated.

11. Apparatus as recited in claim 6, wherein:

the sample and hold circuit is configured to sample envelope amplitudes having voltage values less than a voltage limit;

the peak-to-peak voltage values of the ON mode pulses exceed the voltage limit; and

the detector is configured with a plurality of stages, each of the stages is configured to attenuate the voltage values of the ON mode pulses so that the voltage values of the amplitudes of the envelopes are less than the voltage limit.

12. Apparatus as recited in claim 6, wherein:

each ON mode pulse consists of RF cycles; and

the detector comprises a circuit configured with a storage device and a diode network, the diode network enabling the storage device to store for each cycle a value representing the peak-to-peak voltage of the cycle.

13. Apparatus as recited in claim 6, wherein:

the pulsed RF bias signal comprises RF cycles;

the detector comprises a peak-to-peak detector circuit;

the detector circuit is configured with a pair of oppositely conducting diodes and a capacitor for storing a charge proportional to the peak-to-peak voltage values of the cycles of the ON mode pulses of the pulsed RF bias signal;

each of the diodes is configured with a capacity to conduct current up to a current limit; and

the detector further comprises a separate circuit in series with each of the diodes, the separate circuits are configured so that each of the diodes conducts current up to the current limit as the capacitor is charged.

14. Apparatus for measuring a pulsed RF bias signal applied to a bias electrode of a wafer processing chamber, the apparatus comprising:

a detector configured for response to the pulsed RF bias signal, the pulsed RF bias signal consisting of pairs of ON mode pulses, each pair being separated by an OFF mode, each ON mode pulse consisting of cycles, each cycle being characterized by a voltage amplitude that varies with respect to time, the detector being configured so that the response is generating a detector signal in the form of successive envelopes, amplitudes of one of the envelopes consisting of amplitude values that are proportional to peak-to-peak voltage values of the cycles of a respective one of the ON mode pulses, the amplitudes of a respective envelope being with respect to time only during a respective ON mode pulse, each envelope being independent of a duty cycle and of a frequency of the pulsed RF bias signal; and

a sample and hold circuit configured for operation with respect to each of successive ones of the spaced envelopes at a sampling time when a characteristic peak-to-peak voltage value occurs in each envelope, the characteristic peak-to-peak voltage representing a maximum peak-to-peak voltage of the envelope of each individual detected pulse, the sample and hold circuit sampling an envelope amplitude having an amplitude value proportional to a characteristic peak-to-peak voltage value of the cycles of the respective ON mode pulse and holding the sampled amplitude value until sampling of a next envelope, the sample and hold circuit generating an output signal having a value proportional to the characteristic peak-to-peak voltage value of the cycles of the respective ON mode pulse, the output signal being used for holding electrical characteristics of a plasma steady during processing to compensate for a variation of an

impedance presented to the electrode.

15. Apparatus as recited in claim 14, the apparatus further comprising a timing circuit configured to generate a trigger signal for triggering the sample and hold circuit on completion of a rise period and of a transition period of each of the respective envelopes.

16. Apparatus as recited in claim 14, wherein the sample and hold circuit is configured with:

a sampling module that samples a plurality of successive values of the amplitude of the respective envelope; and

a selecting module that determines which of the plurality of sampled amplitude values is the characteristic peak-to-peak voltage value of the cycles of the respective ON mode pulse.

17. Apparatus as recited in claim 16, wherein the selecting module is configured:

to make the determination with respect to two sampled amplitude values of the peak-to-peak voltage value of the cycles of the respective ON mode pulse and to hold the higher value sample;

to make the determination with respect to the held higher value sample and a sample of the next successive amplitude value of the cycles of the respective ON mode pulse and to hold the higher value sample; and

to stop making the determinations when the sample of the next successive amplitude value is less than the higher value of the held sample and to hold the higher value held sample for use in generating the output signal having a value in proportion to the characteristic peak-to-peak voltage value of the cycles of the respective ON mode pulse.

18. Apparatus as recited in claim 14, wherein for each of the respective successive envelopes the sample and hold circuit samples a characteristic envelope amplitude value proportional to a characteristic peak-to-peak voltage value of the cycles of the respective ON mode pulse to which the respective successive envelope corresponds; and

the apparatus further comprises an averaging circuit configured to obtain a sum by adding the characteristic amplitude values of a preset number of the respective successive envelopes, wherein the preset number is selected so that an update time period during which the output signal is updated equals the number of successive envelopes divided by a pulse rate of the pulsed RF bias signal, the averaging circuit being further configured to divide the sum by the preset number to generate the output signal having a value that is proportional to an average of the characteristic peak-to-peak voltage values of the cycles the ON mode pulses that correspond to the preset number of respective successive envelopes.

19. Apparatus for measuring voltage values of a pulsed RF bias signal applied to a bias electrode of a wafer processing chamber, the signal consisting of an ON mode pulse followed by an OFF mode followed by another ON mode pulse and continuing in a series of alternating ON mode pulses and OFF modes, a pulse rate defining times at which successive ones of the ON pulses start, each ON mode pulse consisting of cycles, each cycle being characterized by voltage values that vary with respect to time and that include a peak-to-peak voltage value of the cycle, the apparatus comprising:

a detector configured for response to each ON mode pulse of the continuing series for generating a detector signal in the form of one envelope corresponding to each of the ON mode pulses and spaced from other successive envelopes according to the pulse rate, each envelope representing peak-to-peak voltage values of the cycles of a respective one of the ON mode pulses, the detector being configured so that the detector

signal consists of one envelope followed by a successive one OFF mode followed by one envelope in a continuing series of OFF modes and envelopes alternating at the pulse rate;

a sample and hold circuit configured to be triggered for operation only with respect to each successive one of the envelopes, the triggered circuit sampling a voltage amplitude value of a respective envelope and holding the sampled value during the next OFF mode, the held sampled value representing the characteristic peak-to-peak voltage value of the cycles of the ON mode pulse corresponding to the respective envelope, the characteristic peak-to-peak voltage representing a maximum peak-to-peak voltage of the envelope of each individual detected pulse; and

a feedback circuit for adjusting a voltage of the pulsed RF bias voltage signal applied to the electrode according to a difference between an output of the sample and hold circuit and a desired voltage value of the RF bias voltage signal to hold the electrical characteristics of plasma steady during processing to compensate for a variation of an impedance presented to the electrode.

20. Apparatus as recited in claim 19, further comprising:

a feedback circuit for controlling the voltage values of the pulsed RF bias signal applied to the bias electrode, the feedback circuit generating a control signal at an update rate, the update rate being slower than the pulse rate and defining a time period between updates of the control signal.

21. Apparatus as recited in claim 20, further comprising:

an averaging circuit responsive to a number of the held voltage amplitude values representing the characteristic peak-to-peak voltage values of the cycles of respective successive ON mode pulses corresponding to respective envelopes occurring in succession during one of the update time periods, the averaging circuit generating an

average of the held voltage amplitude values to represent an average of the characteristic peak-to-peak voltages values of the ON mode pulses during the one update period; and the feedback circuit updating the control signal in response to the average of the held voltage amplitude values.

22. Apparatus as recited in claim 21, wherein the averaging circuit obtains a sum of the held voltage amplitude values held during the one update time period and divides the sum by the number of the held voltage amplitude values to determine the average.