The Reactive Ion Etching of Au on GaAs Substrates in a High Density Plasma Etch Reactor

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ABSTRACT

The etching of Au using photoresist masks and hard masks on GaAs substrates was investigated using a dual frequency high density plasma etch reactor. The advantages of plasma etch techniques over current methods for Au metalization include the ability to simplify the metallization process flow with respect to resist lift-off schemes, and the ability to cleanly remove etched material without sidewall redeposition, as is seen in ion milling. Several different etch chemistries, along with other experimental factors, were considered in this study. Specifically, the etching of Au on GaAs substrates using combinations of Hydrogen Bromide (HBr), Chlorine (Cl_2), and Argon (Ar) was evaluated by observing the etch rates, etch selectivities and the etch profiles obtained with these mixtures. HBr/Ar chemistry combinations were found to have a significant influence on the etch profile of Au, primarily by generating heavy sidewall polymers. The Cl_2/Ar chemistry was found to generate less sidewall polymer during Au etching. The introduction of Cl_2 increases the etch rate of Au and reduces sidewall veil deposition. The Au etch rate and profile were further impacted by the level of RF power applied to the reactor. The best process results obtained to date include etch profiles exceeding 75° with no sidewall redeposition.

INTRODUCTION

Several different materials can be employed for interconnect metallization in the fabrication of integrated circuits. Aluminum and its alloys, tungsten, copper, platinum, and gold have all found use in the semiconductor industry as thin-film conductors. The choice of one material over another for specific applications will be determined by considering the many performance results which need to be optimized for any conductor layer. The essential film properties which determine performance include film electrical resistivity, mechanical and chemical stability, adhesion characteristics, film deposition considerations, and the ease with which the film can be patterned. Copper and gold offer several notable performance features: they both are low resistivity materials (1.7μΩ-cm for Cu; 2.2μΩ-cm for Au), and both provide excellent endurance against electromigration-related failures.[1] Copper is beginning to be used as the material of choice for leading-edge ULSI logic circuits, where R-C delays in device interconnects detract from other gains which have been realized in improving device performance.

Gold has not been much used for interconnect metallization in silicon based devices. Gold is, however, employed extensively in GaAs device fabrication, principally because of its high electrical conductivity and its property of relative chemical inertness.[2] Gold metallization requires the use of adhesion layers, like titanium or chromium; barrier layers are also encountered, often in conjunction with thin platinum films.

Thin film patterning methods fall into two broad categories: subtractive processes, and additive processes. Subtractive patterning involves removal of the thin film layer from areas not protected by a photoresist or other mask. Wet chemical etching, plasma etching, and ion milling are all examples of subtractive patterning techniques. Additive processes include various electroplating schemes, selective film depositions, and photoresist lift-off processes.

GaAs device makers have used lift-off techniques almost exclusively for patterning gold films. The reasons for the success of lift-off include the chemical resistance of gold to wet chemical etchants, making its wet etch problematic, and the problems of film redeposition and poor selectivity to underlying and masking layers associated with ion milling.[3] Advanced lift-off schemes have evolved, with considerable complexity to their process flow[4], which is a chief disadvantage for them over the simpler subtractive removal of gold, should processes exist in which these established plasma etch tools and techniques could be used.

The plasma etch of gold on silicon substrates using photoresist masks and various hard mask structures has been reported for etch chemistries employing chlorine- and fluorine-containing reactants.[5,6] Ranade et al. obtained gold etch rates of almost 1000Å/min using CF_4-CCl_4 mixtures in an RIE plasma etch tool operating at 100mTorr. Etch profiles were primarily anisotropic, with selectivities of 2.0:1, 4.0:1, and 2.7:1 between gold and

photoresist, silicon dioxide, and silicon nitride etch masks. Aldridge, also using an RIE plasma etch tool, experimented with gold etching at pressures between 50mTorr and 500mTorr using CCl_2F_2 or Cl_2 etch chemistries with silicon dioxide or photoresist etch masks. The best results were obtained with pure Cl_2 processes and silicon dioxide hard masks, with gold etch rates reported of up to 9800Å/min and selectivities to the silicon dioxide hard mask of up to 11:1. Etch profiles were anisotropic.

The present work is motivated by an interest in observing the etch characteristics of gold on GaAs substrates under low pressure (5mTorr) high density plasma conditions. These etch conditions have been proven useful in the plasma etching of other noble metals, like platinum and iridium, which are now finding use in integrated circuit fabrication.[7]

EXPERIMENTAL

The plasma etch reactor used for the work reported here is a commercially available dual-frequency magnetically confined high density plasma system (Figure 1).

13.56MHz RF power is applied to the reactor's wafer electrode to produce the dissociated, reactive, and ionized components of the etching plasma. 450kHz RF power is applied to the wafer electrode to controllably extract electrically charged species from the plasma region. Both RF frequencies are controlled independently; a combiner circuit allows for their concurrent transmission into the plasma reactor. Some further characteristics of the Dual-Frequency RF scheme are presented in Figure 2.

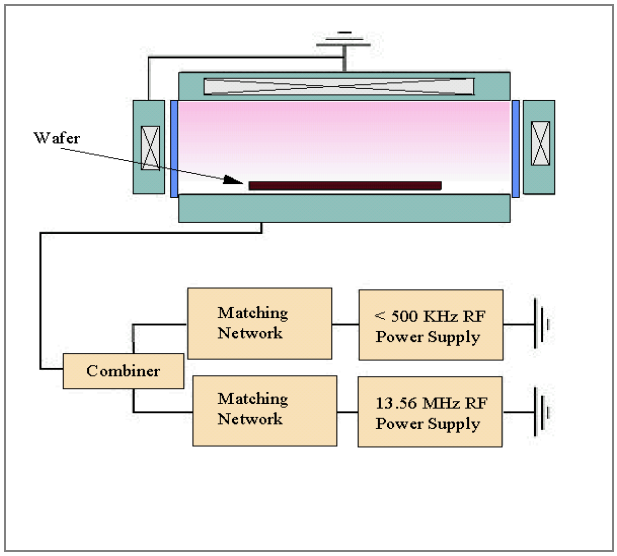

Figure 1. Dual-Frequency Plasma Reactor

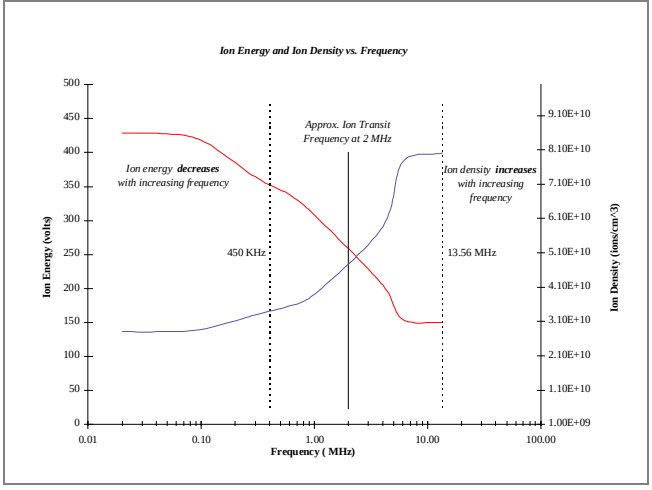

Figure 2. Dual Frequency RF Characteristics

The reactive plasma density is augmented at low operating pressure (1mTorr - 15mTorr) through the use of magnetic confinement. Permanent magnets mounted on the reactor sidewall and grounded top electrode act to reflect escaping free electrons back into the active plasma region, thereby increasing the useful life of the electrons in the reactor and extending their contribution toward enhancing plasma density. This specific implementation of a high density plasma reactor is called HRe$^-$, for High density Reflected electron.

Symmetrical process vacuum with high gas conductance is attained in the dual-frequency reactor by placing a turbo molecular vacuum pump directly above the etching chamber. Closed-loop pressure control is accomplished with a throttle valve, capacitance manometer, and dedicated pressure controller. The wafer temperature control system consists of a mechanical wafer clamp, backside helium flow, and a temperature-controlled coolant recirculator.

The HRe$^-$ plasma reactor is mounted on a cluster tool core; the core can be configured to accept two plasma etching modules (for parallel or series operation), along with a photoresist ash module and a wet rinse station.

DISCUSSION

PHOTORESIST MASK GOLD ETCH

Process feasibility studies of photoresist masked gold etch were started in the dual frequency reactor using stacks composed of 4000Å gold over thin Pt over a Ti adhesion layer over SiO_2 on 100mm GaAs substrates. Photoresist thickness was approximately 10,000Å. The photoresist received a UV cure treatment prior to etch. The first set of chemistries explored combinations of HBr and Ar using a single etch step to clear the gold layer. Etch step termination was indicated by optical endpoint emissions from the plasma. Screening studies with the HBr-based chemistries, while encouraging in their ability to produce vertical etch profiles, all revealed a consistent fault: heavy sidewall deposition, also known as veils, after post-etch removal of the photoresist mask. Figure 3 is representative of the degree to which the veils obscured the other, more positive results of the HBr/Ar chemistries. The veils seem

to be composed of etch product which failed to completely volatilize at these operating conditions, resulting in their subsequent redeposition along the photoresist sidewall.

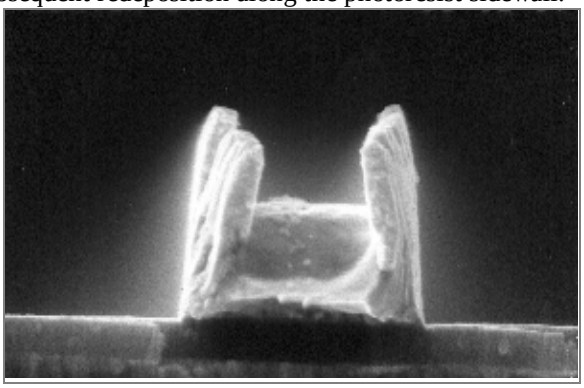

Figure 3. HBr Process Post-etch Veils (Photoresist Removed)

A second set of screening experiments, this time based on Cl_2/Ar etch chemistries, was performed using the same test wafer structure, run again with a single etch step terminated at optical endpoint. Figure 4 illustrates the tendency of the chlorine processes to produce less-forbidding veils than the hydrogen bromide process under similar reactor settings. Also noted is the tendency of the chlorine chemistries to produce more sidewall taper (etch profiles not as vertical) than is the case with hydrogen bromide.

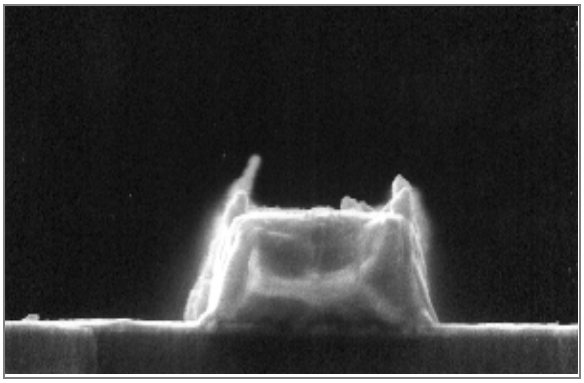

Figure 4. Post-etch Veils with Chlorine Process (Photoresist Removed)

Further screening for effects associated with the other significant process variables available to the experimenter for the case of gold etch with photoresist mask are summarized in Table 1.

	Effect			
Factor	**Profile**	**Veils**	**Au Rate**	**Au:Resist**
HBr Flow ⇑	⇑	⇑⇑⇑	⇒	⇑⇑
Cl_2 Flow ⇑	⇓	⇓	⇑	⇓
kHz Power ⇑	⇑	⇑⇑	⇑	⇒
Mhz Power ⇑	⇒	⇑	⇑⇑	⇑

Table 1. Summary of Screening Experiments Photoresist Mask Gold Etch

Figure 5 is an image of the best result obtained in the series of photoresist mask gold etch experiments. The gold etch rate here is 3500Å/min, with a platinum etch rate of half that. The etch is noticeably veil-free after photoresist strip. The etch profile is approximately 75°. This result was obtained with a two-step etch process. Process conditions: 2mTorr pressure, Cl_2 / Ar mixture, MHz and kHz power both in the optical endpoint step, with a timed overetch run with modified RF power settings.

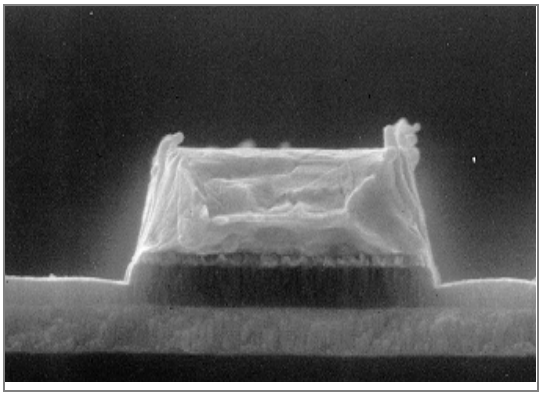

Figure 5. Chlorine Process Best Result (Photoresist Removed)

HARD MASK GOLD ETCH

Hard mask materials have been used extensively in place of photoresist masks for various semiconductor fabrication operations. In the case of plasma etching it may be that the vigorous etching chemistries required for the etching of relatively nonvolatile thin film materials employ combinations of reactant gases, RF power levels, and wafer temperatures which effectively render a photoresist mask useless. The photoresist mask cannot withstand the plasma environment. An early reference to hard masks used for silicon etching describes etch conditions with high ion bombardment and low operating pressure[8] in which a hard mask offered performance advantages over photoresist. A second advantage to using hard masks, particularly in the case of materials which form relatively nonvolatile etch products, is that a thin hard mask offers no site for etch product redeposition, effectively eliminating veil formation.

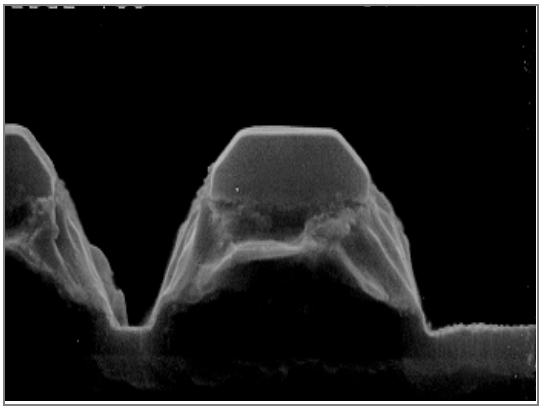

Figure 6. Gold Etch with Thick Hard Mask

Figure 6 shows a result from screening experiments, where a thick hard mask substitutes for the photoresist mask used previously. The results here were not judged to be significantly better than had been obtained with the photoresist (and perhaps thick hard masks like this are at a disadvantage in the post-etch process flow).

After replacing the thick hard mask above with a thinner structure, a set of screening experiments similar to those described previously were run with the Cl2/Ar etch chemistry. The intent was to understand which process variables most influenced sidewall taper and gold etch rate. Veils were nonexistent in this round of work, as was expected when thin hard masks were used.

Table 2 is a summary of the process trends observed using the thin hard mask wafers.

	Effect	
Factor	**Profile**	**Au Rate**
Cl_2 Flow ⇑	⇓	⇑
Ar Flow ⇑	⇓	⇑
kHz Power ⇑	⇓	⇑
Mhz Power ⇑	⇓	⇑

Table 2. Summary of Screening Experiments Thin Hard Mask Gold Etch

The process trends developed in the round of thin hard mask gold etch screening experiments were applied together to optimize the gold etch results. Figure 7 shows an image in cross section of gold etch using a thin hard mask which has been optimized for etch profile, residue, and underlying film loss. Figure 8 is a field view of a similar structure.

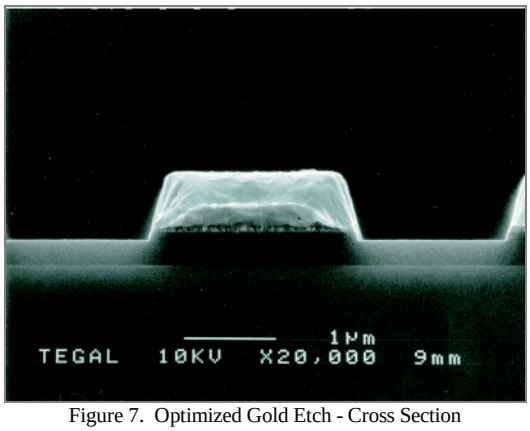

Figure 7. Optimized Gold Etch - Cross Section

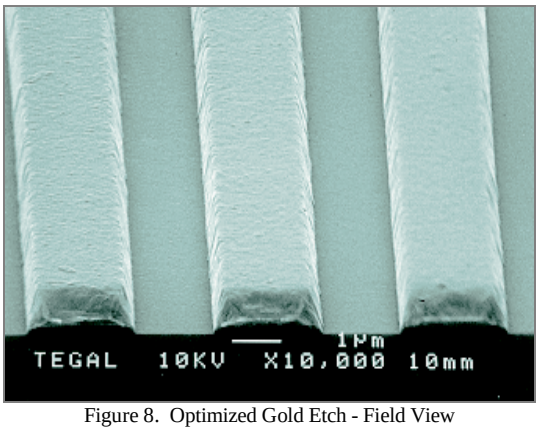

Figure 8. Optimized Gold Etch - Field View

CONCLUSION

Gold etch on 100mm GaAs substrates using a high density plasma reactor has been characterized for the case of both photoresist and hard mask gold stack structures. Etch chemistries based on hydrogen bromide tended to produce heavy sidewall deposition films, resulting in unacceptable residue, veils, after photoresist strip. Chlorine chemistries were more successful with photoresist mask gold etch, although sidewall deposition was also apparent. Hard mask gold stack structures, particularly for thin hard masks, showed more promising process results; significantly, sidewall deposition-related etch residues were not observed during process optimization. A process with good balance between gold etch rate and etch profile was developed for the thin hard mask stack structure.

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