A Highly Accurate Endpoint Method for a TFT Back Channel Recess Etch

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Abstract

We present experimental results validating a new technique that achieves accurate endpoint for a TFT back channel recess etch. These results show a 90% reduction in the standard deviation of final channel thickness as compared to timed etches.

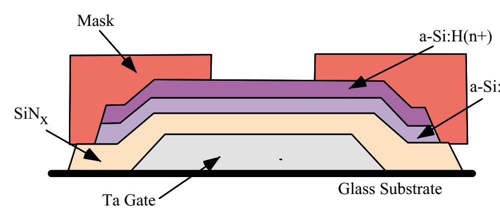

Figure 1: Structure of back channel TFT before channel etch

1 Introduction

In this paper we present experimental results validating a new technique that achieves accurate endpoint for a key plasma etching step in the manufacture of thin film transistors (TFT). During a back channel recess etch, it is desired to remove a film of n+ a-Si:H on top of undoped a-Si:H, without etching the underlying material. (See Figure 1.) Without an endpoint signal, a timed etch must be used. This necessitates the deposition of a thick intrinsic layer to ensure enough material remains for the channel after etching, despite variations in the deposition and etching steps. This thicker layer is undesirable, as it will increase the series resistance to the source and drain ohmic contacts, degrading the device current drive.

To reduce the intrinsic layer thickness in a manufacturable technology, many high performance AMLCD's currently employ the trilayer TFT process. However, the trilayer process requires an additional photolithography step vs. the back channel recess process. If a back channel etch process could be developed with sufficient remaining depth accuracy and sufficient etch uniformity, this simpler process flow could be adopted, and potential increases in throughput and reductions in costs could be achieved. We will report on a new technique for very accurately etching to a desired remaining intrinsic aSi:H layer thickness. This technique is highly robust to variations in the incoming layer thickness and the etch rate in the RIE.

Endpoint can be difficult to achieve using standard techniques. An etch chemistry which is highly selective to the doped layer over the intrinsic a-Si:H is not known. This is expected since intrinsic a-Si:H and n+ doped a-Si:H are quite similar. In order to apply an OES endpoint technique, an emission line corresponding to an etch by-product needs to be identified. Glueck et. al [1, 2] have identified the 240nm line as a potential line to distinguish the n+/intrinsic interface. However, we have not been successful at reproducing this result in our reactor. Also, it may be desirable to use non-CF_4 etch chemistries to improve the n+ a-Si:H to intrinsic a-Si:H selectivity. A wafer level sensor approach, such as ours, will not be sensitive to changes in the etch conditions.

Instead, we have investigated the use of dual wavelength laser reflectometry, whereby two lasers of different wavelengths are directed toward the plate in-situ, and the reflected light intensity is monitored in real time. (See Figure 2.) Standard use of reflectometry signals, however, is not possible. In standard practice, endpoint is called when a set number of fringes has passed or when a sharp slope change occurs because the etch has reached the interface between two layers of contrasting refractive index [3]. The former technique is not accurate enough at the wavelengths for which a-Si:H is transparent, while the latter situation does not hold because of the sim-

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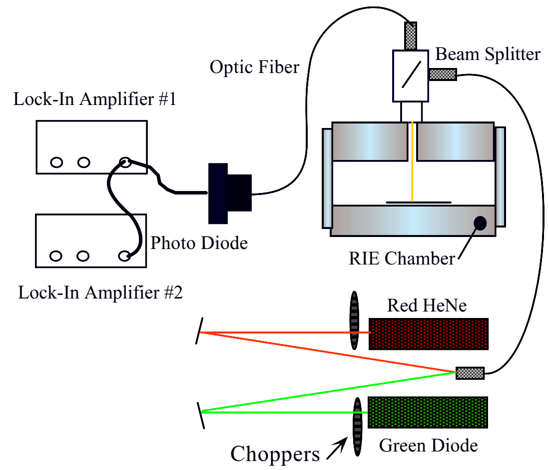

Figure 2: Dual wavelength laser reflectometry implementation.

ilarity between doped and undoped a-Si:H refractive indexes. We have used instead a method of processing the reflected light intensity in real time (every 50 ms) to obtain accurate film thickness measurements. Thus, it is possible to endpoint at any desired remaining film thickness. This method is based on Extended Kalman Filtering, and will be termed EKF-R. The algorithmic details of this method are reported in [4, 5].

The goal of the experiments described here was to quantify the reduction in the variance of remaining a-Si:H using an EKF-R endpoint as compared to timed etches, which are current standard practice. These experiments were exploratory in nature, and we approximated somewhat the material stack of the TFT, as well as used blanket (unpatterned) plates. The details of the experimental conditions, including the material stack, are discussed in Section 2. The results along with discussion then follow in Section 3.

2 Experiment

The experimental vehicle was a Plasma-Therm Clusterlock 7000 RIE located in the Center for Display Technology Laboratory at the University of Michigan. This reactor was integrated into a cluster tool environment, where a robotic arm inside a central transport chamber under vacuum can transport the substrate from process to process, or to a loading module. The RIE had a large (5300 cm^2) powered electrode area designed for processing flat panel displays. A PECVD system was also integrated into the cluster tool.

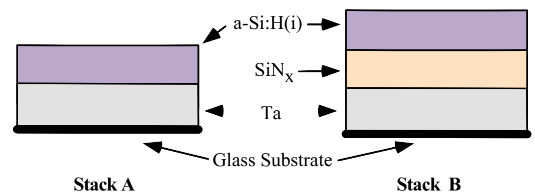

Figure 3: Simplified structures used in experiments

We used two different material stacks (see Figure 3), one, which we will call stack A, which consisted of ~3000 Å sputtered Ta on a glass substrate, followed by ~1000 Å of PECVD a-Si:H, and a second stack, stack B, which included a middle layer of ~3000 Å of PECVD SiN_x. Because of the refractive index of doped a-Si:H is similar to intrinsic a-Si:H, a doped layer was not added, as it would not affect the aim of the experiment. Tantalum was first sputtered on 350×400 mm glass using a Leybold ZV6000. Sputtering time was six minutes at a pressure of 0.005 mbar. PECVD of SiN_x and a-Si:H was performed in the PlasmaTherm Clusterlock 7000 deposition chamber, the former for 30 min at 430 mT, 15 sccm SiH_4, 200 sccm NH_3 and 400 W, and the latter for 8 min at 430 mT, 200 sccm SiH_4, and 90 W. The a-Si:H was then etched using the PlasmaTherm 7000 etch chamber with 100 sccm CF_4, 50 mT, and 700 W as the process condition.

The inputs for the reflectometry system were a 25mW red HeNe laser (632.8 nm) and a 10 mW green diode laser (532.0 nm). The laser output was combined into an optical fiber bundle and then transmitted through the top electrode by quartz rods approximately 3 inches long and 0.5 inch in diameter. A beam splitter with collimating/focusing lenses was used to direct the beam onto the plate in the chamber and the reflected light onto a second fiber, with which it was transmitted to the photo diode. The laser light was chopped at different frequencies (about 800 Hz and 1200 Hz), enabling the signals corresponding to the different wavelengths to be recovered by lock-in amplifiers tuned to the respective modulating frequency.

Two sets experiments were performed, one for each stack. The first set of experiments used stack A and consisted of 20 etches, 10 with the endpoint algorithm and 10 timed etches. The order of experiments was chosen randomly. Timed etches ran for 100 s, while EKF-R endpointed etches were stopped when the algorithm indicated the remaining thickness was 500 Å. The length of the timed etches was chosen to etch down roughly to the desired endpoint of 500 Å, but was not optimized. This is because the performance metric of interest was the variance of the remaining film thickness, since any bias in the mean values of either method could be easily accounted for by adjusting the time of the etch or the desired set-point respectively.

The second set of experiments used stack B, with 10 etches, half timed and half EKF-R endpointed, again with a nominal 500 Å desired endpoint. With these experiments, the EKF-R algorithm must be able to determine the thickness of the a-Si, despite possible variations in the SiN_x layer which could alter the reflected light response. To account for this, The SiN_x layer thickness was also estimated using the EKF-R algorithm, to the nearest 50 Å .

An approximate initial thickness was required to initialize the EKF-R algorithm, and was chosen to be 1000 Å of a-Si, and 2900 Å of SiN_x (if present). It should be noted that the measured initial thickness of a-Si varied by up to 10%, however, the initial thickness measurement was not fed to the endpoint algorithm.

3 Results

Each experiment was performed over a period of about one week. For independent verification of the experimental results, the initial film thicknesses were measured using a Leitz MPV-SP spectrophotometer, while the final thickness values were determined with a Sopra GESP-5 spectroscopic ellipsometer (SE). Limitations on the size of the plate precluded the use of the SE for initial thickness measurements. The accuracy of the SP measurements was limited by the calibration sample, and is ±20 Å or better. The measurements were rounded to the nearest 10 Å. The SE measurements for stack A were determined using an optical model stack of SiO_2/a-Si:H/TaO_x/Ta with the top three thicknesses variable. For stack B, the model stack included a variable SiN_x layer.

The results for stack A are listed in Table 1, and displayed graphically in Figure 4. The maximum .95 confidence interval for the SE a-Si measurement was 4.0 Å.

The primary result of interest is the reduction by 90% of the standard deviation of final a-Si thickness for the EKF-R endpointed etches as compared to the timed etches, from 59 Å to 6 Å. The spread of thickness given by the maximum a-Si thickness minus the minimum a-Si thickness for the EKF-R endpointed etches was only 16 Å. Some of the variance in the timed etches is due to the variation in initial thickness. It is important to note that for the EKF-R endpoint, variations in the deposition process do not have an impact on the final thickness, as they do for the timed etches. This is one of the most significant advantages of this new endpoint method.

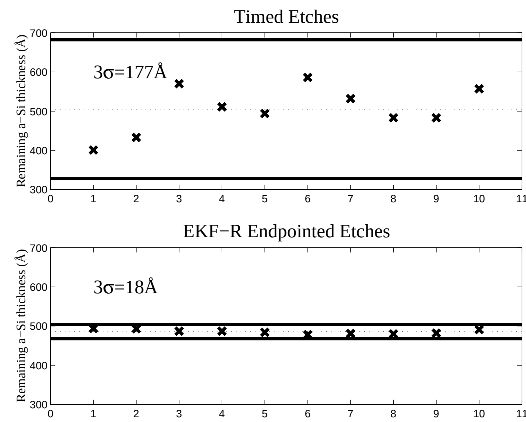

Figure 4: Endpoint results for stack A. The upper plot displays the final a-Si thickness with 3σ limits for timed etches, and the lower plot displays the EKF-R endpointed etches.

The results for stack B are listed in Table 2 and displayed in Figure 5.

EKF-R Endpoint			Timed Etches		
Etch #	Initial a-Si (Å)	Final a-Si (Å)	Etch #	Initial a-Si (Å)	Final a-Si (Å)
1	1000	494	3	900	401
2	970	493	4	940	433
5	1020	487	6	1010	570
7	1000	487	9	1010	511
8	990	487	10	1000	494
11	1020	478	15	1070	586
12	1050	481	16	1030	532
13	1070	480	17	980	483
14	1060	482	18	980	483
19	1030	491	20	1050	557
$\bar{x}$	1020	486	$\bar{x}$	1000	505
σ	32	**6**	σ	50	**59**

Table 1: Experimental results for stack A.

EKF-R Endpoint				
Etch #	Etch Time	Final a-Si (Å)	EKF-R SiN_x (Å)	SE SiN_x (Å)
2	98.8	475	2950	2966
3	103.6	489	2950	2911
4	105.1	485	2950	2929
6	104.0	484	2850	2834
8	121.0	479	2900	2917
$\bar{x}$		482		
σ		**5**		

Timed Etches		
Etch #	Etch Time	Final a-Si (Å)
1	100	420
5	100	535
7	100	550
9	100	700
10	100	617
$\bar{x}$		564
σ		**104**

Table 2: Experimental results for stack B.

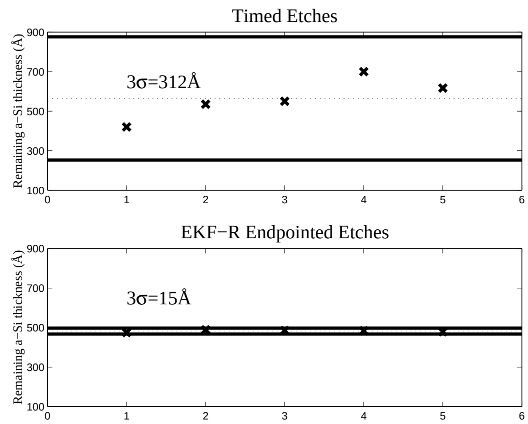

Figure 5: Endpoint results for stack B. The upper plot displays the final a-Si thickness with 3σ limits for timed etches, and the lower plot displays the EKF-R endpointed etches.

Although the data set is not as large as for the first experiment, there is no evidence that the added complexity of the material stack causes a reduction in the accuracy of the EKF-R endpoint. In each case, the EKF-R algorithm was able to estimate the SiN_x thickness to within 50 Å, and standard deviation of the final a-Si:H thickness was 5 Å, with a maximum a-Si minus minimum a-Si spread of 14 Å.

4 Conclusion

We have presented experimental results demonstrating a 90% reduction in final intrinsic a-Si thickness after a back channel recess etch by using a new endpointing method, EKF-R. The main focus of our future work will be to investigate the extension of the EKF-R endpoint method to patterned plates. These results hold the promise of making the backchannel etch TFT more manufacturable while decreasing the channel thickness.

5 Acknowledgements

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