Using Low Coherence Interferometry to Identify and Measure Unintended Voids Introduced During the Manufacturing Process and Provide Feedback to Refine Processes, Minimize Voids, Maximize Yields, and Reduce Costs

Grant Proposal

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Abstract (RQ) or Executive Summary (Eng)

Within this study, we will attempt to correlate the features of voids formed in semiconductors with the failure rate in high-volume semiconductor manufacturing. We will be able to improve the manufacturing process and provide a greater understanding of what voids do and why. This is extremely important to the semiconductor industry, as it will drive less waste, higher yields, lower prices for consumers, and more profits to semiconductor company shareholders. We will do this using infrared interferometry (IR) and statistical tests to find correlations between the features of voids, the effect they have on semiconductors, and where voids are formed during the manufacturing process.

Introduction

A semiconductor is the part of a computer chip that controls whether the chip is on or off. The amount of energy going into the semiconductor determines whether it will be an insulator or a conductor. Semiconductors are one of the most important pieces of technology in the world, as they allow devices to process and store information. Without semiconductors, things like iPhones and computers would most likely not exist. A semiconductor is made by stacking silicon wafers on top of each other. During the manufacturing process, errors can occur, such as air or moisture getting trapped. These errors result in voids, which are micrometers in length and are not visible to the human eye. The effect of a void ranges from no impact to destroying its functionality and rendering the semiconductor useless. Today, semiconductors with voids are disposed of as part of the manufacturing process. This study attempts to identify these voids and the correlation between the relative location of a void, where in the manufacturing process it was introduced, and its effect on the semiconductor.

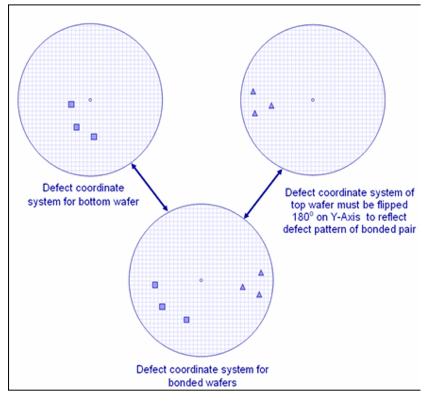

Figure 1: This is the location of voids among different levels of a semiconductor (Rudack et al., 2010)

Our research is rooted in past studies, the first of which led us to the measurement strategy we plan to use. It was seen that IR (infrared interferometry) would be the most accurate measurement for this study, as it is considered an industry standard and is more straightforward to utilize compared to measurement techniques like SAM (Scanning Acoustic Microscopy).(Poduje et al., 2010) IR works by shooting an infrared light into the semiconductor and uses the amount of light that reflects back to measure the voids. Previous studies have looked at the correlation between where semiconductor voids are relative to a bond ball and how this proximity can cause cracks within the semiconductor. Ball bonds are connections between silicon and the packaging on the silicon, so cracks can have a devastating effect on the semiconductor. (Kuo, et al., 2004) Our study will primarily help with high-volume manufacturing, during which many semiconductors are manufactured at once. Although you would assume high-volume manufacturing would lead to a higher yield, this is not always true due to the number of voids introduced during the process. (Siddiqui et al., 2017) Other studies have looked at the relationship between the size of a void and when it will crack a semiconductor (100 UM). (Kuo et al., 2004) Although that data is useful, it does not paint the full picture as manufacturers still do not fully understand the impact of voids relative to their location on the chip and where in the process they were introduced. Another study looked at how effective a semiconductor is based on how aligned its silicon wafers are, and how that correlates to voids forming. (Rudack et al., 2010)

This research has inspired our study's methodology, which will begin by acquiring some semiconductors and wafers that have failed void testing, meaning they have voids. We will test the semiconductors and wafers to verify failure. After that, this study will use IR to measure the depth of each semiconductor and use that data to identify void locations, as a change in depth represents a void. We will also measure how close these outlier depths are to different parts of the semiconductor, such as bond balls. We will then create a program that can automatically analyze the data and calculate the correlation of the semiconductor’s voids and how the semiconductor is affected by them. We will repeat this process and attempt to get a broad data set, which will lead to an understanding of how voids, based on size and location, affect a semiconductor. To identify the part of the manufacturing process during which the voids were introduced, we will use a different methodology. We will measure depth after each step in the manufacturing process. This should leave us with a data set from which we can derive manufacturing issues that lead to void formation. With this data, we can attempt to help manufacturers improve processes, reduce voids, and increase semiconductor yields.

The results from our study could link the location of voids and their effect on semiconductors more thoroughly. It could also provide a greater understanding of what is going on within semiconductors during manufacturing and help manufacturers refine production processes. Increasing the yield would lower the cost of semiconductor technology, while simultaneously reducing the amount of pollution caused by the semiconductor industry. This would affect the whole technological market, leading to lower prices for all computing devices and indirectly improving the world's economy.

Section II: Specific Aims

This study's objective is to find a correlation between the location and size of voids within semiconductors, the effect they have on a semiconductor's functionality and purpose, and the manufacturing step or mistake that led to a specific void forming.

Our long-term goal is to discover the effect of voids based on size and location. The central hypothesis of this proposal is that the larger the void and smaller the distance to important parts of the semiconductor (such as electrical connections) the less efficient the semiconductor will be (up to and including complete failure). The work we propose in the study is to scan for these voids using IR, and then analyze the resulting data.

Specific Aim 1: Refine, develop, and compare the most accurate methods to identify voids, measure voids, find the location, and calculate the distribution of voids.

Specific Aim 2: Analyze how the size and proximity to certain parts of a semiconductor affect its purpose, performance, and the likelihood of a failure occurring.

Specific Aim 3: Determine the specific steps within the manufacturing process that led to certain voids forming and refining this process based on this information.

The expected outcome of this work is to prove that infrared interferometry (IR) is an effective way to measure and locate voids within semiconductors. I also believe that the larger and closer a void is to electrical connections like bond balls or other important parts of a semiconductor will lead to decreased performance and an increased likelihood of failure. Lastly, we will be able to become more knowledgeable about the reasons voids form by correlating the development of voids to specific steps in the manufacturing process.

Section III: Project Goals and Methodology

Relevance/Significance

This project is relevant due to the major knowledge gap within the semiconductor industry on the effect of voids. Some companies understand what some voids do, but there is no clear guidance on voids from a cause-and-effect perspective. There is little research on the correlation between the features of a void (such as void size, proximity to key semiconductor parts, and when introduced during the fabrication process) and the effect on semiconductor quality and performance.

Innovation

This is a huge innovation within the industry as before my study there was almost no public research available that correlates the relative location of a void and its impact on the effectiveness of the semiconductor. This will be one of the first studies to be publicly released and it could drive major changes within the semiconductor manufacturing and disposal processes.

Methodology

1. Use infrared interferometry to detect the location of voids within a semiconductor, measure their size, and identify their location relative to specific parts of a semiconductor.

2. Compare the effectiveness of semiconductors by putting different electrical charges through the semiconductor within a circuit.

3. Do T-tests to compare the effect the features of a void have upon the semiconductors within the circuit and determine if it is statistically significant.

4. Do a T-test to see if there is a statistically significant difference between different manufacturers.

5. If there is a statistically significant difference between different manufacturers, find out what they do differently and attempt to design the most ideal manufacturing process with this information.

Specific Aim #1:

Determine the most effective method for scanning and identifying voids within semiconductors. The objective is to find the most accurate way to find voids in semiconductors and measure their location, size, etc. Our approach (methodology) is to compare different methods using research articles and possibly test their accuracy. Our rationale for this approach is due to the extensive research already published on this subject. This will ensure we use an industry-standard practice but also prove it ourselves for our specific use case.

Figure 2: This is an example of a form of an IR display. (Allen et al., 2010)

Justification and Feasibility. With an IR scan of a wafer with known voids, we can compare the location of actual voids to our detected ones. We can see how accurate our measuring is and if it is statistically significant within the data. Having this evidence allows us to confirm our choice of measuring methodology.

Summary of Preliminary Data. There have already been a few studies comparing the methods of identifying voids. These studies have compared their accuracy which we can replicate by using IR on a wafer with known voids.

During preliminary testing, we found that IR was an accurate form of measurement as there was a strong correlation between the coefficient of light and actual depth in nanometers of the calibration discs.

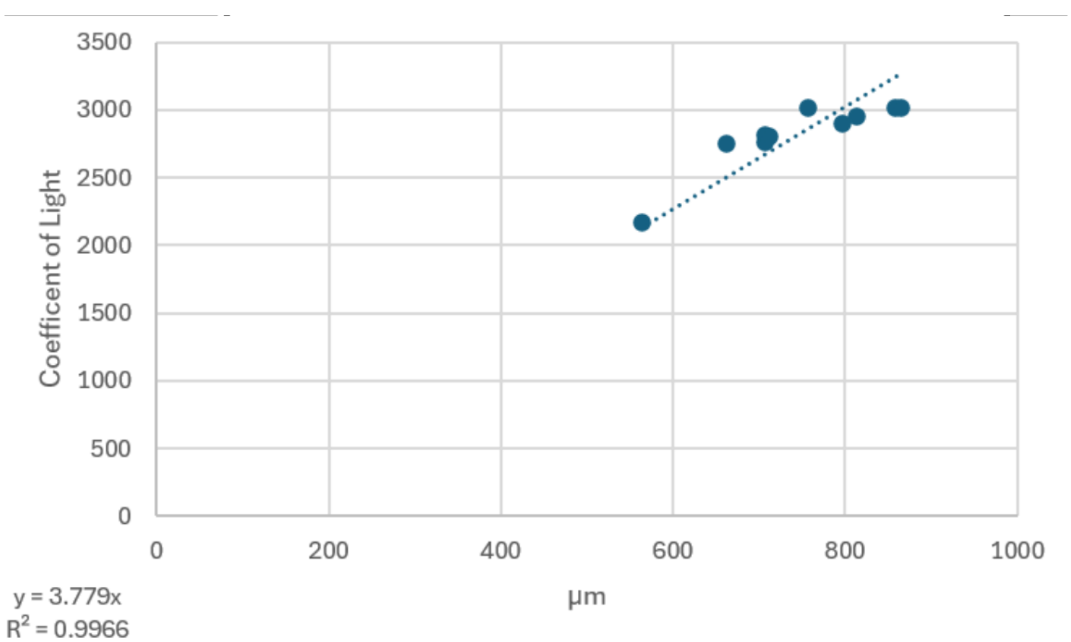

Figure 3: This graph represents the linear relationship between the coefficient of light and nanometers of thickness of the premeasured calibration discs. This data was collected during preliminary testing using IR on calibration discs.

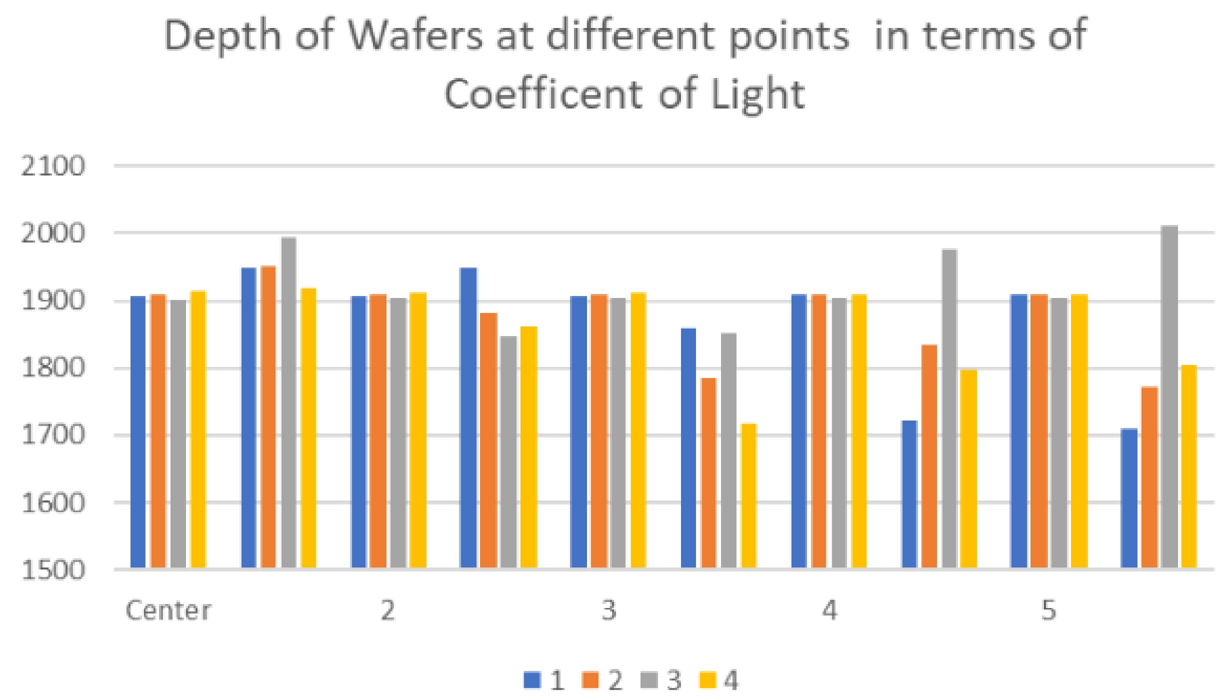

Figure 4: This bar graph shows the coefficient of light from multiple spots on four different wafers. Data was collected during preliminary testing using IR on spots on wafers.

Expected Outcomes. The overall outcome of this aim is to find the most accurate way to find voids and to prove that it is the most accurate way. This knowledge will be used for what methodology will be used going forward.

Potential Pitfalls and Alternative Strategies. We expect IR to be the most effective method for measurement. It is also the only technology to which I currently have access. However, if testing leads me to believe it is an inaccurate measuring tool I will attempt to get access to SAM.

Specific Aim #2:

Determine the effect that relative location, size, and other void features have on the efficiency, purpose, and failure rate of semiconductors. Our approach (methodology) is doing an IR scan and then doing a statistical analysis of the data received. Our rationale is if there is statistically significant evidence leading to a correlation between the effect and the void features, we can make assumptions about which void features cause specific issues.

Justification and Feasibility. The reason this methodology is feasible is because the measurement strategy is considered accurate proven in Specific Aim 1. With this knowledge, I will find voids within a semiconductor and then compare them to the effect they have on the semiconductor. I will use factors such as size, location, relative location, etc. If there is a correlation between these factors, I will perform a statistics test to see if it is statistically significant.

Summary of Preliminary Data. Research has already been done in this area but in a much narrower scope, such as looking at the impact of voids that are close to bond balls (A. F. Said et al., 2010) Studies like these are the basis for my wanting to broaden the scope to look at the correlation of multiple void features, their impact, and when they are introduced during the manufacturing process.

Expected Outcomes. The overall outcome of this aim is to see if there is a correlation between the features of a void within a semiconductor and the use of a semiconductor. Based upon previous studies and basic logic there will most likely be a correlation between voids and the use of a semiconductor.

Potential Pitfalls and Alternative Strategies. We expect there to be a correlation between voids and the use of a semiconductor, but there could not be. There could be other factors that I am not measuring that could affect the data, like lost waveguides due to through tunnels. (Kasaya et al., 1996)

Specific Aim #3:

Determine the effect that different manufacturing processes have upon the void formation and the reason for these different void formations. Our approach (methodology) is to find a correlation between the voids formed and which step in the manufacturing process they occurred. Our rationale is if there is statistically significant evidence leading to the correlation between the voids formed and the manufacturing process, we can improve all manufacturing processes by combining the parts that lead to the best ending.

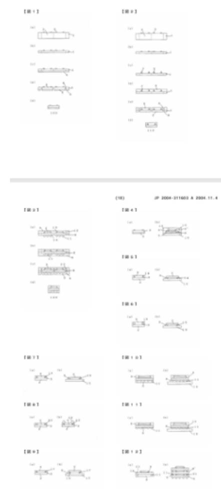

Figure 5: This is an example semiconductor production process from for a semiconductor grant. (Takahashi et al, 2004)

Justification and Feasibility. The reason this methodology is feasible is a basic statistical test. We will attempt to correlate the voids formed and the manufacturing step that produced them. We will then use this information to create a manufacturing process that reduces the number of voids formed.

Summary of Preliminary Data. This is one of the end-game tests that will be completed in this project. I have not been able to confirm any semiconductor manufacturer who would like to assist me in this study.

Expected Outcomes. The overall outcome of this aim is to see if there is a correlation between different voids and the specific manufacturing steps that caused them. I believe there will be voids tied to specific steps, but I also believe that different manufacturers use different steps. By combining the steps with the least void formations from across manufacturers, we could create a better semiconductor manufacturing process.

Potential Pitfalls and Alternative Strategies. There are a lot more potential pitfalls within this aim. I may not hear back from any of the semiconductor manufacturers from which I have sought assistance. There could also be alternative manufacturing processes in play (such as water-level packaging) that could significantly affect the data. (Th et al., 2009) There may also be other manufacturing problems that aren't caused by voids.

Section III: Resources/Equipment

1. Semiconductors (enough for statistically significant data)
2. Low coherence interferometry machine
3. Info on the manufacturing process that the semiconductors where produced
4. A wafer with semiconductor die
5. Access to semiconductors throughout the manufacturing process
6. Access to multiple semiconductor manufacturing process

Section V: Ethical Considerations

All important safety procedures are met. There is no danger within the experiments and they are easy to be produced and overseen by professionals. More investigation needs to be done to the user of equipment being exposed to infrared light.

Section VI: Timeline

The timeline for this study is on Trello: https://trello.com/b/ZsbL4C5O/danny-stuff

Section VII: Appendix

Supplementary to this proposal is some preliminary IR data showing measurements of a wafer. It provides measurements of the X, Y, and Z axes, as well as other information. We will extrapolate wafer depth from this data to identify voids and then use math modeling and data science techniques to analyze and draw conclusions.

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41846.6	159.998	168.098	5	1344.24	1343.33	892.413	974.713	314.241	0	0	0	0		4.10E+08
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41846.6	159.998	168.42	8	1344.36	1193.29	125.094	459.564	881.877	478.713	181.316	34.9346	0		4.09E+08
41846.6	159.998	168.465	7	1344.37	1193.6	874.89	870.6	156.339	206.516	54.0145	0	0		4.08E+08
41846.6	159.998	168.533	8	1343.58	593.037	655.214	689.743	89.7197	324.611	278.059	54.0841	0		4.08E+08
41846.6	159.998	168.585	9	1344.83	138.088	17.1792	1062.22	233.276	261.935	208.352	162.5	75.539		4.08E+08
41846.6	159.998	168.63	6	1344.4	1192.86	275.675	1067.31	676.476	143.345	0	0	0		4.08E+08
41846.6	159.998	168.683	8	1344.29	892.001	244.055	1133.95	485.565	181.681	47.1985	34.6847	0		4.11E+08
41846.6	159.998	168.735	9	1344.73	138.507	165.547	863.335	354.731	186.208	207.017	151.08	92.9407		4.11E+08
41846.6	159.998	168.78	7	1343.45	443.741	934.768	391.134	396.289	296.174	54.1893	0	0		4.10E+08
41846.6	159.998	168.833	7	1343.42	293.962	1216.5	148.201	219.691	379.852	90.1394	0	0		4.08E+08
41846.6	159.998	168.885	9	1344.35	139.727	462.88	648.094	407.757	220.718	164.092	99.2634	34.6681		4.12E+08
41846.6	159.998	168.938	6	1343.36	143.443	1198.98	368.755	396.483	71.8947	0	0	0		4.08E+08
41846.6	159.998	169.005	8	1343.5	293.634	1066.86	197.205	509.076	175.866	87.1108	17.6341	0		4.10E+08
41846.6	159.998	169.05	7	1344.13	893.207	649.008	786.281	416.714	86.5859	17.9178	0	0		4.09E+08

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