High-k Technology

Iain Buchanan

Welcome to another podcast from Air Products. I'm Michael Danese. Today's topic is High-k technology. Iain Buchanan is here with us today, and he has been with Air Products for eleven years. He is a PhD chemist and is an Applications Manager for our Advanced Integration Materials group in our Electronics Division. He's here today to talk about to Air Products' offering in high dielectric constant materials for advanced memory devices. Iain, thanks for being here today.

Thanks, Mike.

For years, the industry has made much of silicon's almost unique characteristic which makes it so suitable for semiconductor manufacturing – the existence of a good quality oxide. Now we hear about High and Low-K films. What is this about?

Until now, we've been able to enhance device performance by shrinking features, but we're reaching the limits of physical scaling and are having to employ materials science to keep on track. For interconnect, the metal lines connecting the device together have become so close together that the increased electrical capacitance between them slows the device down. AP have enabled the industry's progress in this area through development of our PDEMS film, which has a lower dielectric constant (or K Value) than SiO2. For the active components in the device, the transistors and capacitors, the opposite problem arises. We need to switch or store the same amount of electrical charge (representing a binary 1 or 0) using a smaller area than before. Increasing the K Value of the dielectric is a useful way of doing this, hence the move away from SiO2 to other dielectric materials.

Isn't it possible to achieve the same effect by folding the device in three dimensions to maintain the surface area?

Yes, this has been done for some time. Focusing on the DRAM capacitor, we've been moving from a planar, parallel plate capacitor to cup or cylinder structures with increasing aspect ratios. Air Products have been instrumental in supporting the demanding etch processes required to form these structures. For example, control of the etch process is enhanced by changing from an Argon to a Xenon based plasma, but Xenon is a lot more expensive than Argon. We introduced our XeCovery^{SM} system which allows us to recover the Xe, reduce the cost and make it more compatible with the economic pressures of DRAM manufacturing. However, we can't rely on folding the capacitor into ever more demanding shapes and need higher dielectric films to keep us on the roadmap.

Iain, what dielectrics are being used and what precursors are available?

The first step was to use Aluminium Oxide which can easily be deposited from Trimethyl Aluminium (or TMAl). This is a textbook ALD process (Atomic Layer Deposition) process. TMAl is a volatile liquid, it's easily delivered to the ALD process chamber. It has good thermal stability and forms a nice saturated monolayer on the high aspect ratio structures without degenerating to a non-uniform or non-conformal CVD process. It has high chemical reactivity so is readily oxidized to Aluminium Oxide. In fact, its high reactivity can be a problem because TMAl is pyrophoric – it spontaneously ignites if exposed to air or moisture, so must be handled with caution. Air Products designed the ChemGuard® 400 chemical cabinet to enable safe handling of this precursor.

The dielectric constant of Al2O3 was sufficient for DRAM devices down to about 90 nm but beyond that a dielectric with a higher K Value was required. Hafnium Oxide was the next to be introduced but it was quickly recognized that its near neighbour in the Periodic Table of Chemical Elements, Zirconium, could offer an advantage. It is possible to crystallise Zirconium Oxide and the crystalline form has a higher K Value than the amorphous (or non-crystalline) form. The only problem with the crystalline form is that it has a higher leakage rate. So, although a capacitor formed with a Zirconium Oxide dielectric can initially store a relatively high electrical charge, the charge leaks across the dielectric too quickly to by useful for practical DRAM devices. But people learned that they could block this leakage by sandwiching about half a nanometre of Aluminium Oxide in the middle of 8-10 nm of Zirconium Oxide, a so-called ZAZ film. This gives the best of both worlds – the high dielectric constant of Zirconium Oxide combined with the low leakage of Aluminium Oxide. It is this combination which serves industry needs today at the 55 nm node.

That sounds great, Iain. Tell me a little bit about TEMAZ.

TEMAZ is the precursor of choice – tetra (ethylmethylamino) zirconium – and it has moderate thermal stability, vapour pressure and chemical reactivity. You can get nice ALD performance with TEMAZ and Ozone up to about 300°C. It's a fairly volatile liquid which can be introduced to batch ALD tools by direct liquid injection – DLI. Not only are Air Products supplying this precursor to our high volume manufacturing customers, but we have also developed a specific ChemGuard® cabinet, the CG500, for this class of precursor.

You mentioned this is working well at 55 nm. What happens at future nodes?

Well it looks like ZrO2 can be extended to 45 nm and some people are hopeful of extending it to 32 nm, but sooner or later a film with a higher dielectric constant is going to be required. If that film can be ready in time, it seems that the industry will be enthusiastic about integrating it for manufacture of 32 nm DRAM beginning in 2010. And that's where Air Products' chemical experts are taking up the challenge. The industry has identified Strontium Titanium Oxide (or STO) as the leading candidate for ultra High K. In contrast with ZAZ, STO is a true chemical substance and not a sandwich film. But there is a significant challenge with STO, which is to identify a good precursor for Strontium.

What is the issue with Sr?

The issue is that Strontium loves Strontium, so rather than form simple molecules with one Strontium atom in them, it likes to form clusters with 2, 3 or more Sr atoms. These are heavy molecules so they're not very volatile and they're also not very chemically reactive. The good news is that our scientists have identified some exciting pieces of chemistry which prevent the Strontium from forming these multinuclear clusters. The resulting precursors are more volatile and more reactive than what we had before and we've begun to demonstrate their use in ALD Depositions.

However, STO isn't the end of the road. We also know that Strontium's neighbor in the Periodic Table of Elements, Barium, can help achieve even higher K Values. This is in the form of another chemical compound, Barium Strontium Titanate, or BST. And although Strontium precursor development has been a challenging chemical problem, we have to acknowledge that Ba precursor development is even more difficult. For that reason, it is unlikely that BST shall be integrated before 22 nm. However, we are confident that Air Products' chemists can solve these problems to help us play our part in keeping the ITRS on track.

Well, Iain, you've covered a lot of information here. Tell me, what is the key message that you want our listeners to come away with?

I'd like our listeners to understand that we have been developing some novel precursors to extend High-k beyond what is being done today into the extreme High-k area of STO and BST.

Okay, that's great. How can people find out more information about Air Products High-k offering?

You can go to our web site at www.airproducts.com/highk, there you can listen to some of our other podcasts or download literature. Alternatively, please feel free to contact me on e-mail at Buchani@airproducts.com.

Okay, that sounds great. Once again, that website is www.airproducts.com/highk. And, Iain's e-mail address is buchani@airproducts.com .

Thank you for listening to this Air Products podcast.