



# 4DS Memory Ltd

On the cusp of something significant...

Price: A\$0.038 | Price Target: \$0.055 | ASX: 4DS | 12 October 2016

We see 4DS Memory Ltd (4DS) on the cusp of achieving key milestones over the next 6 months, which could unlock significant value and a share price re-rating. 4DS is involved in the development of resistive random access memory (ReRAM), an emerging non-volatile memory technology. The technology is disruptive and has been earmarked by industry participants to displace incumbent solution NAND Flash (however we note this is a long term proposition). From a broader industry perspective, we see significant opportunity for 4DS to disrupt the cloud and mobile storage space, which is estimated to grow at a 16% CAGR.

- **The Company.** In conjunction with its strategic partner, 4DS is developing a patented, non-filamentary ReRAM technology – called Metal Oxide Hetero Junction Operation (MOHJO) – suited for gigabyte (GB) silicon storage which is smaller, requires less power with increased reliability and performance relative to incumbent data storage solutions, such as NAND Flash.
- **The market.** The majority of non-volatile memory (NVM) storage currently uses NAND Flash (Flash), the predominant storage technology used in mobile phones, tablets and laptops. Due to the proliferation of data consumption, memory storage use is growing exponentially, driven by: increasing use of cloud storage; continued proliferation of mobile devices; increasingly connected devices. Annual global memory market valued at US\$79bn p.a., which is growing at a 16% CAGR. Flash is an estimated annual market of US\$40bn.
- **The opportunity.** It is widely accepted that the existing Flash technology has a diminishing ability to scale further. The industry requires a solution which can scale further, is fast and reliable, and meets the future needs for more storage in less physical space. The industry is seeing a shift from cloud players to silicon storage. While hard drives in the cloud offer a good solution (great retention and recovery), it is power hungry, heat producing and inferior latency.
- **The solution – 4DS ReRAM.** 4DS has developed a scalable non-filamentary ReRAM memory cell at a 50nm lithography, a breakthrough in ReRAM technology. 50nm represents significant progress towards the development of next generation mobile and cloud silicon storage.
- **The strategy.** Over A\$15m have been invested so far in developing 4DS's ReRAM technology since 2007. 4DS owns 16 patents for material composition and deposition process and mechanism of action. Further, 4DS is currently engaged in a joint development arrangement (JDA) with a global storage leader, HGST Netherlands B.V. (HGST), with the goal of optimising their memory cell and manufacturing process. HGST is a subsidiary of Western Digital, a US\$17bn NASDAQ-listed company. The joint development arrangements provide 4DS with the resources and technical expertise which can expedite the development and commercialisation process.
- **Strategic partner is the natural acquirer, in our view.** We estimate Western Digital has invested significantly more in the JDA than 4DS's A\$15m (the company has not disclosed this figure). Further, it is our understanding that Western Digital spent significant amount of time undertaking due diligence into 4DS and its patents. We believe it is the natural acquirer of 4DS. We believe the current share price is not fully appreciating this strategic partnership.

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## Investment Thesis

4DS' share price will be driven by the following factors:

- Short term catalyst #1 – achieving sub-50 nm geometry
- Short term catalyst #2 – achieving endurance targets
- Significant growth estimated in cloud storage and mobile devices
- Transformational and disruptive memory technology
- 4DS's ReRAM technology among the leading next generation players
- Secured key patents to protect IP (first patent expires in 2029)
- Strategic JV partner in Western Digital provides additional expertise and validation, who is also the leading player in the space globally.

## Key Risks

We see the following key risks to our investment thesis:

- Termination of the HGST partnership
- Development risk including technological failure
- Commercialisation risk
- Competing alternative technologies
- Key person risk linked to key executive personnel.

## Company Description

4DS Memory Ltd (4DS) designs, develops, and manufactures non-volatile memory products. 4DS's business is the development of intellectual property pertaining to non-volatile memory storage known as ReRAM (Resistive Random Access Memory) technology, which has the potential, if successfully developed and commercialised, to displace traditional "Flash" memory storage. 4DS owns 16 patents for its technology and materials deposition process, together with several related patents in other key jurisdictions. The Company's R&D is based out of Silicon Valley, USA.

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## Investment thesis

### Significant rise in data storage estimated...

The data storage requirements of the world are estimated to exponentially increase going forward due to the proliferation of technology, data consumption and the connectivity of devices. Annual global memory market is estimated to grow at 16% CAGR.

### Incumbent technology approaching its limits...

The current mainstream technologies – dominated by NAND “Flash” memory (2D and 3D Flash) – have limitations around further scalability (scale down to meet the demand of smaller devices) and meet future storage needs (have physical capacity).

### Experts calling out ReRAM as the viable solution...

ReRAM based disruptive technologies have been called out by industry players and experts as the best potential replacement for NAND Flash. It has the ability to store exponentially more data, is smaller, cooler, faster and utilises less power.

### 4DS's unique solution using ReRAM...

4DS is developing a unique Interface Switching ReRAM technology (non-filamentary ReRAM), which relative to incumbent solutions (i.e. Flash), has scale benefits (i.e. higher density), requires less energy (i.e. lower power consumption), greater reliability & endurance and faster access speed and performance. 4DS has already demonstrated its technology's efficacy at a 50 nanometre (nm) geometry, achieving wafer to wafer and lot to lot consistency using memory cells of varying sizes, representing significant progress in scalability and yield. The 50 nm geometry is in-line with the latest generation of 3D Flash – the most dominant non-volatile memory technology used in billions of mobile devices, cloud servers and data centres. In the coming months, 4DS is confident of achieving sub-50 nm geometry, a key scalability milestone.

### Development and commercial viability through JDA...

Approximately A\$15m has been invested in developing 4DS ReRAM technology since 2007. 4DS is currently engaged in a joint development agreement (JDA) with a global storage leader, HGST Netherlands B.V. (HGST), with the goal of optimising its memory cell and manufacturing process. HGST is a subsidiary of Western Digital, a US\$17bn NASDAQ-listed company, which strategically invests in high growth and emerging technology segments and innovative product development.

### Successful development will catch the attention of acquirers...

Consolidation within semiconductor manufacturers has seen the larger memory makers shift focus from manufacturing to owning intellectual property. This in turn drives acquisitions of successful start-up technology companies, which bodes well for 4DS.

### Western Digital provides a backstop to 4DS's valuation, in our view

We estimate Western Digital has invested significantly more in the JDA than 4DS's A\$15m. Further, it is our understanding that Western Digital spent significant amount of time undertaking due diligence into 4DS and its patents. We believe it is the natural acquirer of 4DS. We believe the current share price is not fully appreciating this strategic partner.

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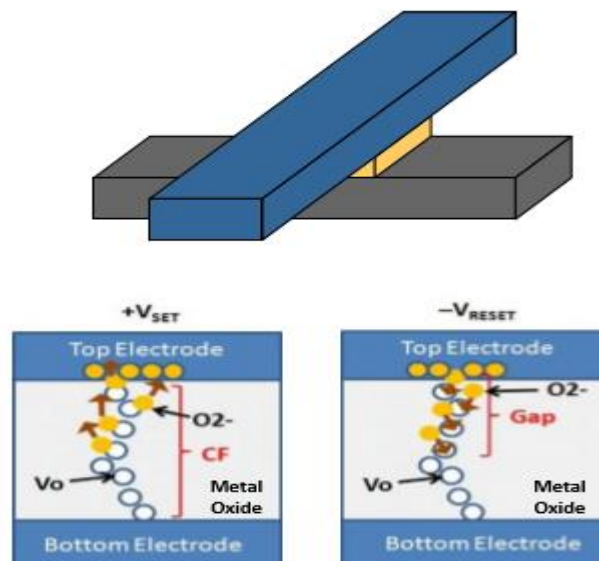
## Company Overview...

4DS is developing intellectual property pertaining to non-volatile memory storage known as ReRAM (Resistive Random Access Memory) technology, which has the potential, if successfully developed and commercialised, to displace traditional “Flash” memory storage. 4DS owns 16 patents for its technology and materials deposition process. 4DS’s Metal Oxide Hetero Junction Operation (MOHJO) technology is a non-volatile memory, where the storage cell can have a high or low resistance.

**So what is different about 4DS technology?** 4DS is developing a unique Interface Switching ReRAM technology (non-filamentary ReRAM), which relative to incumbent solutions (i.e. Flash), has scale benefits (i.e. higher density), requires less energy (i.e. lower power consumption), greater reliability and endurance, faster access speed and performance. From our understanding, due to the make up of 4DS’s technology the likely target markets will be the cloud and data centre storage segments – both of which are going at double digit rate. Data centre space is estimated to grow to 200 million square metres in 2018.

**How does ReRAM work?** ReRAM works by creating resistance rather than directly storing charge. Typically, ReRAM cells consist of a switching material sandwiched between two electrodes. These cells are then arranged in a cell matrix to form a memory array. A voltage is applied to the memory cell causing the resistance to change. The resistive change is reversible by changing the applied voltage. The change in resistance establishes the “On” and “Off” states and is referred to as the “switching mechanism”. The figure below describes a common filamentary switching system used in most ReRAM developments.

**Figure 1: Basic ReRAM cell operation with filamentary switching system**



Source: Company

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The controlled formation and destruction of filaments in large numbers allows for storage of digital data. As the table below highlights, non-filamentary has a number of benefits over filamentary, most of important of which is that the former does not have scaling issues.

**Figure 2: ReRAM – filamentary vs. non-filamentary**

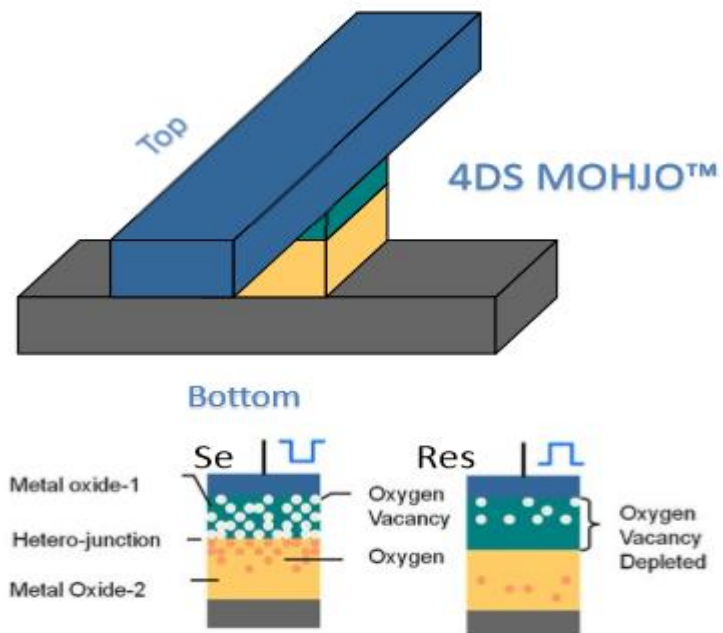
	Filamentary ReRAM	4DS Non-filamentary ReRAM
Switching currents	High and don't scale with cell size	Low and <b>scale with cell size</b>
On-off current ratios	Must be high due to widely fluctuating currents	Can be low due to much <b>more stable currents</b>
Scalability	Limited by wire current densities due to constant switching currents	Lower current allows <b>smaller cells</b> not limited by wire current densities
Cycling endurance	Constant filament formation and destruction results in eventual cell breakdown	Does not rely on a destruction mechanism thereby <b>increasing reliability</b>
Data retention	High switching currents needed for long data retention	Low switching currents <b>help data retention</b>
Market sweet spot	Low density: IoT devices, small embedded memories	<b>High density:</b> GB silicon storage for mobile and cloud

Source: Company

As the table above highlights, ReRAM technology that utilises a filamentary switching mechanism needs to overcome a number of potential shortcomings: (1) lack of control - the filament is a kind of short circuit between the electrodes that is somewhat random and difficult to control; (2) the nature of forming and reforming filaments lead to difficulties with endurance; and (3) As cells get smaller, the filamentary current is the same, leading to larger current densities which restrict the ability to scale down.

**4DS switching ReRAM.** 4DS avoids the above issue altogether because its MOHJO hetero junction does not rely on the formation of a filament.

**Figure 3: Basic ReRAM cell operation with filamentary switching system**



*Figure 2 4DS MOHJO™ heterojunction non-filamentary switching mechanism.*

Source: Company

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The overall MOHJO memory cell reduces and increases its resistance to form the “on” and “off” states. This gives it a number of advantages and makes it a strong potential candidate to replace Flash memory in the future (assuming successful development and commercialisation).

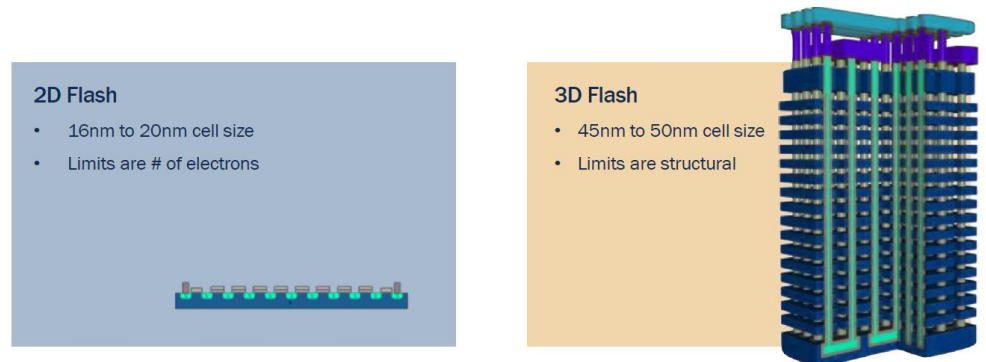
**4DS R&D focus.** In order to demonstrate sufficient progress to indicate that production of commercial product is viable, 4DS must demonstrate scalability (small memory cell size with small space between memory cells) and consistency of its memory cell behaviour. This requires a process of simultaneous and continuous improvement of (i) the memory cell architecture, (ii) the manufacturing process, and (iii) the PCMO deposition equipment, complemented with semi-automated test procedures to gather statistical data for yield analysis, fundamental cell behaviour, cycling endurance and data retention in order to monitor progress. 4DS has already demonstrated a functional cell and lot-to-lot consistency of different wafers with high yield. Yield is the percentage of memory cells in a given array that pass all tests and function properly. 4DS has spent approximately A\$15m has been invested in developing 4DS’ ReRAM technology since 2007. This amount would have been significant higher had it not have a strategic JDA with Western Digital.

**Joint development arrangements (JDA) with Western Digital.** 4DS is currently engaged in a joint-development with a global storage leader, HGST Netherlands B.V. (HGST), with the goal of optimising its memory cell and manufacturing process. HGST is a subsidiary Western Digital, a US\$17bn NASDAQ-listed company. The joint development arrangements provide 4DS with resources and technical expertise which may expedite the development and commercialisation of 4DS’s technology.

### Industry Overview...

Memory underpins everything in the digital world and can be categorised as: volatile memory (used as “core memory” in computers and devices) or non-volatile memory (persistent storage in computers and devices). Increasingly, hard disk drives are being replaced by memory chips and are known as solid state drives (SSDs). The current mainstream technologies is dominated by NAND “Flash” memory.

**Figure 4: 2D Flash vs 3D Flash**



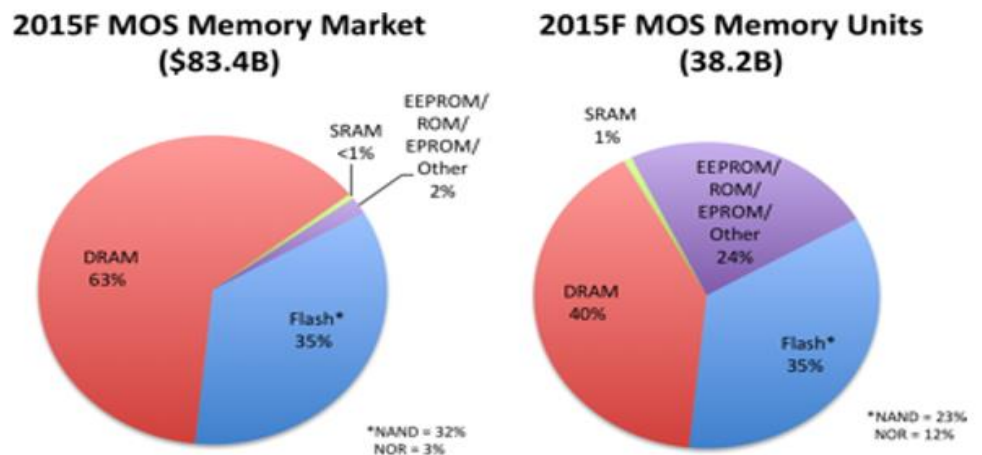
Source: Company

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3D NAND (Flash), which stacks memory cells vertically (rather than horizontally – 2D Flash) is the next step in memory chipmakers' transition to lower-cost technology. 3D NAND helps pack more transistors per square millimetre in a chip. The complexity lowers factory wafer output without additional investment in increased capacity. Samsung is among the early producers, on its third generation, with Micron close behind.

**How big is the market?** The 2015 semiconductor memory market is forecast to be approximately US\$80bn with a CAGR of more than 15%. The leading manufacturers of high volume high-density non-volatile Flash memory are Samsung, Toshiba/Sandisk, SK Hynix and Micron/Intel.

**Figure 5: 2015 memory market breakdown**



Source: Company, IC Insights

Increased demand for data storage capacity is the primary driver of increased demands for higher density memory. This has been driven by the proliferation of smart-phones, tablets and laptops. However, emerging market trends show a changing demographic according to research firms specialising in the semiconductor market:

- Enterprise storage (hosted in private or public clouds) will be by far the largest market by 2020. Cloud data centres, previously contained racks of hard drives, which are now being replaced by SSDs comprised of non-volatile memory.
- The second largest market segment in 2020 is expected to be memory needed for wearable technologies – due to strong demand for low energy memory.

Accordingly, the biggest opportunity for emerging NVM hopefuls, including 4DS, is to replace Flash as the dominant standard for Cloud and mobile use, with a view to target the market for wearable technology (wearables) in the future. Mobile storage is dominant today but its growth will eventually be limited to population growth (and how long users keep the same device). Wearables will increase the amount of memory demand, but this segment too, will eventually be contained to population growth. However, there does not seem to be anything limiting the growth of the storage in the cloud and significant evidence exists to date showing a staggering growth in the amount of data generated and stored worldwide.

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### Company Valuation...

Coming up with a valuation for 4DS is not straight forward. In fact, we question the method in valuing 4DS based on recent transactions given the companies acquired were either revenue generating or struggle to stack up on “apple-for-apple” comparison basis. Given 4DS offers a very disruptive technology, has a strategic partner in a global leader but still has to prove its commercial viability, we have taken a venture capital approach (which we believe is the very conservative approach) to valuing 4DS. We ascribe a value of A\$1.5 – 2.5m to 5 key components of the company. However, for prototype and strategic relations, we have ascribed the total amount spent to date on MOHJO. While it is our understanding that Western Digital has invested significantly more than A\$15m, we prefer to take the conservative approach. Further, given the company is unlikely to roll-out its technology itself, we have ascribed a lower value to this component. We derive a valuation of \$0.055 for 4DS, which we believe is very conservative.

**Figure 6: 4DS venture capital valuation**

Valuation Components	Ascribed Value (A\$m)
1. Sound idea - basic value, product risk	2.5
2. Prototype (reducing technology risk)	15.0
3. Quality Management Team (reducing execution risk)	2.5
4. Strategic relationships (reducing market risk and competitive risk)	15.0
5. Product Rollout or sales (reducing financial or production risk)	1.5
<b>Total Value</b>	<b>36.5</b>
# of shares outstanding (million)	659.2
<b>Value per share (A\$)</b>	<b>\$0.055</b>
<b>Upside to current price</b>	<b>45.7%</b>
# of fully diluted shares outstanding (million)	833.0
<b>Value per share (A\$)</b>	<b>\$0.044</b>

Source: Company, BTIG

For the sake of completeness, however, we have listed below recent transactions in the industry and current valuation of listed players in the ReRAM landscape. There is a valid argument that 4DS should trade on a premium to its listed peers given it has a strategic partnership with the global leader in the memory space.

**Figure 7: ReRAM universe**

Company	Exchange	Market Cap	Type	Target Market
Crossbar	Private	na	Filamentary ReRAM	Internet of Things, wearables, SSDs
Weebit Nano / Radar Iron	ASX	A\$30.4m	Filamentary ReRAM	Internet of Things, wearables
Adesto Technologies	NASDAQ	US\$35.7m	Filamentary ReRAM	Internet of Things
Strategic Elements	ASX	A\$31.6m	Nano cube ReRAM	Printable memory
4DS Memory	ASX	A\$25m	Non-filamentary ReRAM	GB silicon storage for mobile/cloud

Source: BTIG, Bloomberg, Company



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While we have not explicitly included a takeover premium in our valuation, we believe the most likely outcome for 4DS is a takeover approach once the company hits its key milestones.

**Figure 8: Recent transactions**

Acquirer	Transaction	Date	Value (US\$)	Technology	Market
Western Digital	Acquired startup Virident	2013	\$685 million	Flash controllers	Cloud
Western Digital	Acquired sTec	2013	\$340 million	Solid state drives	Cloud
Seagate	Acquired LSI	2014	\$540 million	Flash controllers	Mobile
Cypress	Merger with Spansion	2015	\$5 billion	Flash memory	Flash systems
Western Digital	Acquired Sandisk	2016	\$19 billion	Flash memory	Cloud

Source: Company



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