

CALIMETRICS, INC.

## Pit Depth Modulation: Multiplying the Capacity and Speed of CDs and DVDs

*In 1983, the compact disc (CD) became the hottest product on the consumer electronics market with the ability to encode over an hour of high-quality audio on each of the silvery discs. A few years later, computer users were equally enthusiastic when CD-ROMs, each with the data capacity to hold entire encyclopedias or the complete works of Shakespeare, first appeared on store shelves. In 1997, the digital video disc (DVD)<sup>1</sup> became the latest in optical storage disc trends by offering a larger storage capacity and faster reading speed than prior CD formats. In this rapidly changing digital revolution, however, the need for the still larger storage in the next generation disc has already become apparent.*

COMPOSITE PERFORMANCE SCORE

*(Based on a four star rating.)*

### Ever-Increasing Demands for More Storage Capacity

Demand for DVDs continues to grow; DVD system sales are estimated to increase from 95 million units sold in 1998 to over 175 million units in 2001.<sup>2</sup> This popularity is not surprising given that a DVD can hold enough data (up to 8.5 gigabytes on a dual layer disc) to play back an entire motion picture on a standard television with far greater clarity than a standard VHS videotape.<sup>3</sup>

A single-sided DVD, however, does not have sufficient capacity to store the same movie at the much greater level of resolution required for high-definition television (HDTV)—which requires 15-20 gigabytes (GB) per disc. The shortfall of storage capacity for HDTV applications represents a large challenge. The recent proliferation of digital technology for other uses, such as audio recordings and computer storage, has created a voracious worldwide appetite for ways to store huge amounts of data.

The fast-moving computer and consumer electronics sectors are highly competitive, promoting widespread demand for digital media and driving the need for more storage capacity. Digital storage is vitally important for delivering telecommunication and entertainment services,

as well as computer programs to households.<sup>4</sup>

Given the high stakes, competition among data-storage companies in the United States, Japan, Europe, Australia, and elsewhere is intense. Hundreds of millions of dollars have been spent researching a variety of methods to increase data storage speed and capacity.

### Turtle Ears Lead to Proposed Method

During his doctoral studies at the University of California at Berkeley, from 1988–1993, Mike O’Neill was working on the development of a laser feedback microscope to study the inner ear function in turtles (a turtle’s inner ear is very similar to a human’s). During this time, O’Neill met Terry Wong, another graduate student interested in the laser feedback microscope. Working in the same lab, the two began to see a very different potential application of the laser technology they were developing: to increase data storage.

The following year, O’Neill and Wong, along with Tom Burke, a former McKinsey & Company consultant, founded Calimetrics. The company’s mission was to develop their “pit depth modulation” (PDM) technology to increase the storage capacity and access speed of CDs.

<sup>1</sup> Since the introduction of computer DVD-ROMs, DVD has become “Digital Versatile Disc.”

<sup>2</sup> Source: IDC, Strategic Marketing Decisions, Disc/Trend, Wall Street Journal. <[www.calimetrics.com](http://www.calimetrics.com)>.

<sup>3</sup> The 8.5 GB on a dual layer DVD disc is doubled to 17GB for a dual layer double-sided DVD disc. Although PDM increases capacities to the range needed for HDTV quality content, 17 GB can handle this. ML reduces the cost of media manufacture as compared to the DVD solution, and eliminates the need of turning the disc over in the middle of the movie.

<sup>4</sup> “Optical Storage Technologies,” *TechMonitoring*, 1998 (SRI Consulting).

## PROJECT HIGHLIGHTS

### PROJECT:

To develop pit depth modulation (PDM) technology to triple the storage capacity and reading speeds of existing CDs and DVDs by using multilevel pit depths rather than binary pit depths.

**Duration:** 2/1/95 –3/31/97

**ATP Number:** 94-01-0115

### FUNDING (in thousands):

ATP	\$1,808	66%
Company	945	34%
Total	\$2,753	

### ACCOMPLISHMENTS:

Calimetrics developed data storage enhancement technologies using patented pit depth modulation (PDM) technology and is poised for commercial development. The company:

- developed microchips for existing laser CD readers that can evaluate the intensity of the laser light reflected from the disc, making PDM compatible with existing products on the market;
- developed integrated circuits that can be used in current CD and DVD manufacturing systems to make drives that can read at multiple depths and which add very little to the cost of disc mastering while producing the dramatically improved storage benefits of PDM;
- improved the precise control of the laser depth for the mastering process, by reducing power fluctuations and improving the electronics that turn the beam on and off;
- investigated different materials to sharpen the differences in the pit depths (but did not use them due to market resistance);
- developed new decoding software to interpret optically-stored data and correct errors;
- presented a paper on PDM at the 1997 Optical Data Storage Conference and published articles in multiple periodicals;
- received two patents for project research:
  - “Optical disc reader for reading multiple levels of pits on an optical disc”  
(No. 5,854,779; filed 1/5/1996, 12/29/1998)
  - “Method and apparatus for providing equalization for the reading of marks on optical data storage media”  
(No. 5,818,806; filed 5/6/1997, granted 10/6/1998);
- licensed suite of optical storage technologies to Texas Instruments in August 1999;

- finalized \$12 million in venture capital funding from Walden International Investment Group, JAFCO America Ventures, and others, and two industry veterans, William J. Schroeder (CEO of Diamond Multimedia Systems) and James A. Malcolm (founder and former CEO of Accumap Corporation) joined the Calimetrics Board of Directors; and
- formed strategic agreements with TDK Electronics and other industry leaders for joint development of new products that implement Calimetrics’ advanced multilevel optical storage capabilities.

**CITATIONS BY OTHERS OF PROJECT’S PATENTS:** See Figure 44.

### COMMERCIALIZATION STATUS:

Calimetrics has licensed its technology for commercial use and formed alliances with TDK and other companies for new product development.

### OUTLOOK:

Optical data storage markets are expanding. Annual shipments of DVD systems worldwide are expected to increase from 95 million units in 1998 to 175 million units by the end of 2001. Calimetrics is positioned to take advantage of this expanding market through strategic alliances with leading disc drive, disc media, and integrated circuit manufacturers. The company’s alliances with Texas Instruments and TDK Electronics for joint new product development are important steps towards commercializing the new storage capabilities. At the same time, the technology has disseminated to others through publications and patents.

The advantages of larger storage capacity and faster read speeds offered by PDM technology will be available to those in the data storage industry for a relatively low incremental cost. Calimetrics has designed this technology to be both backward and forward compatible. It will work with existing CD and DVD systems, while also supporting the latest (and anticipated) laser technologies. With commercialization plans for the near future and strategic partnerships established, Calimetrics’ PDM technology appears poised to make a strong impact in the expanding optical data storage market.

**Composite Performance Score:** ★ ★ ★

### COMPANY:

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**Contact:** Tom Burke

**Phone:** (510) 864-4100

**Number of Employees:** 3 at project start; 10 at project end; 35 as of January 2000

When first starting out, O’Neill and Wong had confidence in PDM’s technological potential, but the fledgling company did not have the means for sustained research. With a kick-start of \$25,000 from family and friends, the company sought funding from venture capitalists and other private sources. All, however, rejected investment in PDM development, deeming the technical and market risk too high. The company faced the classic catch-22 situation of innovation financing: funding was not available because the technology was unproven, yet it could only be proven if substantial financial resources were brought to bear on the problem.

In 1994, Calimetrics became aware of ATP, submitted a project proposal to develop PDM technology, and won. With a \$1.8 million award from ATP, and a smaller grant from the state of California’s Trade and Commerce Agency, Calimetrics took on the challenge of developing the technology born of the earlier laboratory experiments of the two graduate students.

### Achieving Compatibility with Industry Standard Production Methods

O’Neill, Wong, and Burke knew that attempting to redirect the entire CD market toward a new technology would

be a formidable task for a small company, even if they could raise research funding. They, therefore, made the decision to pursue applications of the technology that would be compatible with existing CD manufacturing processes and usable with existing CD readers.

Standard compact discs are manufactured by spinning a fine layer of light-sensitive material (photoresist) onto a clean glass disc. The disc is then baked to remove the solvent. Next, the coated glass disc is engraved by a laser, creating pits in a binary (pit or no pit) pattern, thus encoding information onto the disc. In the next step, the exposed photoresist is developed and washed away, and a thin layer of metal is sputtered over the master. The final stage involves growing a thicker metal layer through galvanic action on the master disc that ultimately forms the teeth of the die used to replicate or stamp out the pits on CD copies.<sup>5</sup> The lasers in disc systems read the lack of a pit

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edge as a “0” and the presence of a pit edge as a “1,” making music or pictures from encoded streams of these numbers.

Building on this technique, DVDs have increased optical storage capacity over CDs because they have smaller, more densely packed pits on each disc. A CD-ROM holds only 650 megabytes (MB) of data that can be read at a speed of 3 MB per second (on a 20X drive). A dual-layer DVD-ROM holds 8.5 GB of data.<sup>6</sup>

PDM technology expands and extends on the DVD advances by creating multiple-level pits that have eight possible depths, rather than just two. This increase multiplies the disc’s storage capacity and the rate at which the data is read. Using advanced circuits, PDM pits are engraved by adjusting the intensity of the laser to generate a desired pit depth: the greater the intensity, the greater the pit depth. By increasing the number of pit depths from one to eight, PDM triples the storage capacity, as each PDM pit provides the same amount of information as three traditional binary pits. It also enables the retrieval of information at three times the speed of traditional CDs since the laser scans the PDM-enhanced pits at the same

speed, with three times the data content.<sup>7</sup> PDM technology increases the standard CD-ROM storage space and retrieval time from 650 MB at 3 MB per second to 2 GB of data at 9 MB per second.<sup>8</sup> Similar improvements are also possible with DVD: storage capacity can be increased from 8.5 GB to 18 GB per side on a dual-layer disc, and read up to two times faster.<sup>9</sup> The increase in storage capacity and read time provided by PDM technology will help keep optical storage discs up to pace with software innovations and HDTV advances.

To achieve compatibility with existing products in the optical storage industry, Calimetrics created new microchips that can be incorporated into current CD and DVD readers and manufacturing systems to enable them to work with PDM technology. Drive designs were modified to be able to evaluate the intensity of laser light reflected from the discs and, therefore, read multiple depths. This strategy of making their new disc technology work with existing readers and manufacturing systems was key for a small company like Calimetrics to be able to enter into the marketplace effectively.

Other core innovations included increasing the precision of laser depth control during the disc mastering process by reducing power fluctuations and improving the electronics that turn the beam on and off. Coupled with better lasers, new decoding software was also developed to interpret data and correct errors. Additionally, Calimetrics investigated various materials for sharpening the differences in pit depths. They discovered, however, that market acceptance required standardization of materials to those already in use.

The related group of supporting technologies developed by Calimetrics is expected to allow PDM to stay compatible with expected future technologies such as shorter wavelength lasers, faster spindle speeds, dual lasers, and multi-layer discs. In contrast, the research being done by other data storage companies has focused more on the development of completely new types of lasers to read discs. PDM and its laser-reading software represent a cost-effective solution that can be produced

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<sup>5</sup> Description by the company at <www.calimetrics.com>.

<sup>6</sup> A single-layer DVD holds 4.7 GBs of optical data.

<sup>7</sup> *Design Engineering*, September 1997, p. 11.

<sup>8</sup> “3-D Pits Boost Optical Storage,” *Photonics Spectra*, July 1997, <www.PhotonicsNet.com>, updated by Calimetrics, December 1999. (For Calimetrics’ first product, the increase in read speed will be limited to 5.4 MBs because of electronic limitations.)

<sup>9</sup> Matthias Henneberg, “Optical Storage Technologies,” *Tech Link*, July 1997 (SRI Consulting).

and marketed by major DVD-drive manufacturers without major equipment changes. The PDM-related modifications increase the capital cost of a disc mastering machine by only about 1 or 2 percent, while creating a 300 hundred percent improvement in storage capacity and read time.

**ATP Funding Nurtures PDM in A Rapidly Changing Market**

While Calimetrics was developing PDM, concurrent technological changes were occurring in the optical storage industry. Researchers developed phase-change technology, a process that takes advantage of the changes in reflectivity of a new optical disc surface as it changes between an amorphous and a crystalline state. Information is read from the phase-change discs by discriminating between the dark amorphous zones and the bright crystalline zones. Phase-change technology has been embraced by industry as a low cost, marketable technology for rewritable DVDs and CDs.

In October 1997, demonstrating both its nimbleness and the broad applicability of the technology, Calimetrics combined phase-change technology with the ATP-funded PDM technology to produce a new multilevel (ML) technology. ML enables PDM encoding on rewritable and write-once optical storage systems. The ML technology enabled Calimetrics to keep up with the movement within the DVD-CD industry for rewritable and write-once CDs and DVDs.

**Industry-wide Recognition for PDM**

Calimetrics publicized its PDM work soon after the fruits of research were demonstrated. The company received two patents for its PDM research conducted with ATP funding, which complement the two original patents that the company licenses on an exclusive basis from University of California, Berkeley, and the multiple patents that it has received after its ATP project.

Presentations by Calimetrics have contributed industry-wide knowledge of PDM technology. Company researchers made presentations at the 1997 Optical Data Storage Conference in Tucson, Arizona. In addition, PDM technology has been featured in articles in various publications including *Data Storage* magazine, *Popular Science*, and the *Wall Street Journal*. Further impact will be gained through Calimetrics’ membership in the National Storage Industry Consortium (NSIC), a group of 60 of the nation’s leading firms, research organizations, and universities dedicated to the advancement of U.S. data-storage technologies.

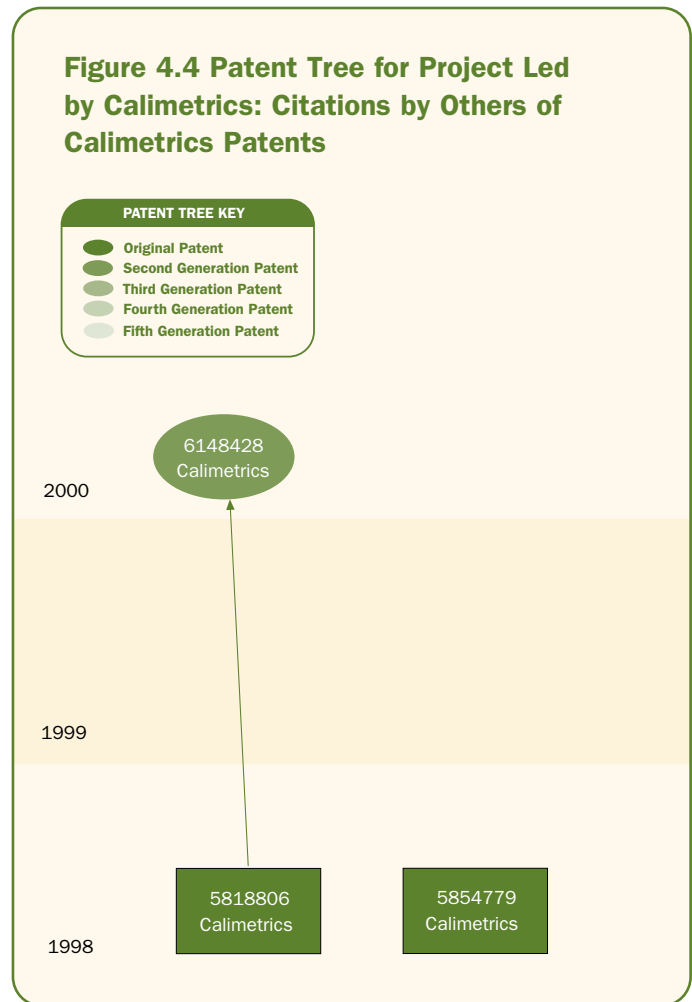
**Technology Alliances to Commercialize PDM Technology**

Texas Instruments (TI) licensed PDM and ML technology from Calimetrics in August 1999. Calimetrics has also formed strategic partnerships with leaders in the disc drive

and media industry. It has successfully attracted new venture capital and corporate investment.

On October 30, 2000, TDK Electronics Corporation, a Japanese-owned company, announced the creation of a technology alliance with Calimetrics, Inc., to apply Calimetrics’ ML technology to create a new recordable and rewritable optical disc format with three times the capacity and three times the speed of conventional CD-R/RW recording. It was announced that the first products to incorporate the new multilevel recording technology will be a new generation of computer drives. The company president commented, “The dramatic gains in capacity and speed offered by the new ML format make it the ideal bridge to the future... to the era of inexpensive recordable DVD.” At an upcoming Comdex Show in Las Vegas, TDK and Calimetrics will demonstrate the ML recording system for interested drive and media manufacturers, IC manufacturers, OEM suppliers and software developers.<sup>10</sup>

**Figure 4.4 Patent Tree for Project Led by Calimetrics: Citations by Others of Calimetrics Patents**



<sup>10</sup> Business Wire, Port Washington, New York, Oct. 30, 2000.