

# Mastering Beyond DVD Densities

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## New Developments

Recent advancements in shorter wavelength semiconductor lasers and the development of applications requiring vast amounts of storage capacity have initiated the generation of formats with storage densities approximately four times higher than that of DVD. These lasers either employ GaN or frequency doubled IR semiconductor lasers to generate shorter wavelengths in the blue/violet range of the visible spectrum.

Potential applications range from storage and distribution of prerecorded HDTV quality video using ROM formats to digital video recording using recordable (R) or rewritable (RW) formats and hybrid combinations thereof. Prototype players currently under development target storage capacities ranging from 14 – 22 GB per layer for a CD or DVD sized disc (120 mm outer diameter). These capacities allow for approximately twice the picture resolution in both horizontal and vertical dimensions and four times the data rates as compared to the DVD format without compromising quality at comparable total play times.

## Next Generation Formats

Although from an application point of view, extrapolations can be made to determine required storage capacities and densities for these applications, it is clear that the shorter wavelength of the blue/violet laser alone will not meet the density requirements of next generation formats. The fundamental parameter that sets the achievable storage density, which can reliably be read back by the pick-up head (PUH) of the player, is the spot diameter of the focused laser beam at the pitted information layer. The smaller the pits are the smaller the playback spot size needs to be. The spot diameter (at half maximum intensity) for an ideal lens is approximately given by  $0.5\lambda/NA$ , in which  $\lambda$  is the wavelength and NA

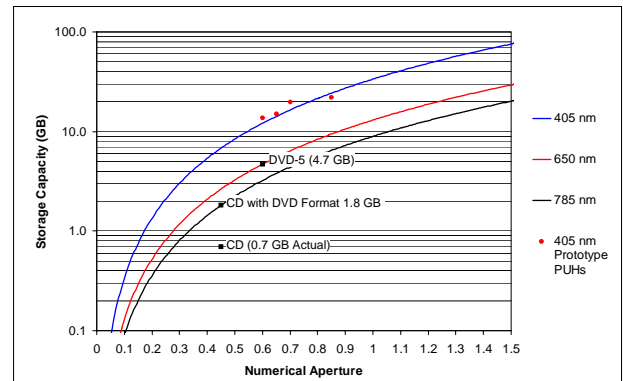


Figure 1. Achievable storage capacities based on the DVD format and margins.

is the numerical aperture or “light gathering capability.” Therefore, by solely reducing the wavelength from the nominal 650 nm used by DVD players to the 405 nm of the (GaN) blue/violet semiconductor laser the storage capacity which can be reliably read out is only a factor of 2.6 higher than that of DVD.

The most straightforward way to further reduce the spot diameter (thereby increasing the storage capacity that can reliably be read back) is to increase the numerical aperture. Figure 1 shows the achievable storage capacity as a function of the numerical aperture for three wavelengths: 785 nm used in CD players (black line), 650 nm used in DVD players (red line), and 405 nm slated for (GaN based) next generation players (blue line). In this comparison it is important to note that these single layer storage capacities are based on the DVD format and margins. Therefore, the storage capacity reaches the DVD-5 capacity of 4.7 GB for a numerical aperture of 0.60, which is the nominal value for a DVD player objective lens. Note that CD player optics ( $\lambda = 785$  nm, NA = 0.45) is capable of achieving a storage capacity of 1.8 GB. This is a factor of 2.7 larger than the maximum actual storage capacity of a CD-ROM of 0.7 GB which is

attributed to reduced (radial and tangential) margin, more efficient encoding, and a slightly smaller start radius of the DVD format as compared to that of CD.

Also shown in Figure 1 (in red dots) are the reported storage capacities for a few prototype pick-up heads and media format combinations currently under development that are based on the blue/violet semiconductor lasers. The reported capacities of these configurations fall near the projected capacities (blue line) for this wavelength and range of numerical apertures. It is possible to achieve even higher capacities (densities) for a given numerical aperture but that would require either reducing the margins below those of DVD or employing new technologies such as more efficient encoding, better error correction, or crosstalk cancellation. Even if the radial and tangential margins are preserved the higher numerical apertures have a large impact on the design of the optical disc medium and its manufacturing process. Specifically the substrate (protective layer) thickness and tilt tolerances need to be taken into account not to induce aberrations which effectively increase the player spot size and reduce player/medium system margins. Again, additional complexity can be added such as tilt servo (already used in Laser Disc players) and active spherical aberration correction. The latter is also an advantage to compensate for the slight substrate (protective layer) thickness differences associated with addressing multiple information layers. As shown in Figure 1 even higher capacities beyond those of the prototype systems could be achieved by employing numerical apertures larger than 1. This would however entail additional sophisticated technology such as near field optics and is probably not likely or perhaps even necessary to launch a next generation format.

### High Density Mastering Requirements and Approaches

As new applications requiring increased storage capacities/densities develop and player technologies based on blue/violet semiconductor technology mature, mastering equipment that support the corresponding smaller pit dimensions is necessary. The pit depth required for these next generation formats is mainly determined by the shorter readout wavelength. To first order the pit depth needs to scale directly with the (effective) wavelength used in order to reliably read back the pits. Since the pit depth is about 120 nm for a DVD read out at 650 nm, the optimum pit depth at 405 nm read out is in the 60 – 80 nm range (assuming a refractive

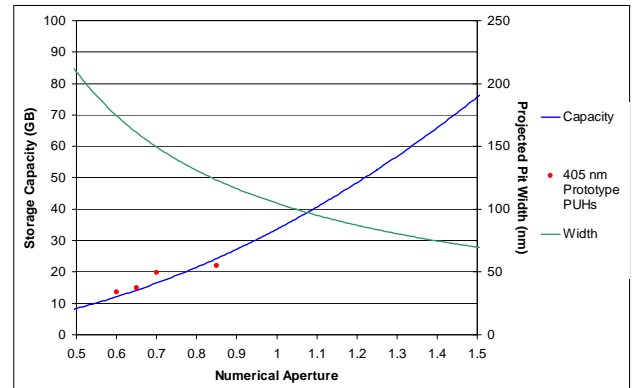


Figure 2. Projected required pit widths for blue/violet semiconductor laser readout at 405 nm wavelength. Storage capacity based on the DVD format and margins.

index of about 1.6 in the protective substrate layer). The pit width required is determined by the spot diameter, which as discussed before is proportional to  $\lambda/NA$ . For a DVD the approximate pit width is about 280 nm measured at half maximum depth. This is about one half of the playback spot diameter at half intensity, which gives good playback signal quality. Using this dimension as a reference, the projected pit width can be calculated as a function of the playback numerical aperture for the blue/violet wavelength (405 nm). Figure 2 shows this projection in addition to the storage capacity again based on the DVD format and margins. For the prototype systems under development the projected pit width are ranging from about 175 nm down to 120 nm. For the upper end of this range, corresponding to about the numerical aperture of DVD, the aspect ratio (height to width ratio) is giving rise to comparable side slope angles of the pits ( $50^\circ - 60^\circ$ ). However, as larger numerical apertures are used the side slopes have to be steeper to avoid any elevated crosstalk or jitter. This will in turn adversely affect the ability to release the stamper from the molded plastic replica without damaging the pits and inducing cosmetic staining (clouding) on the replica.

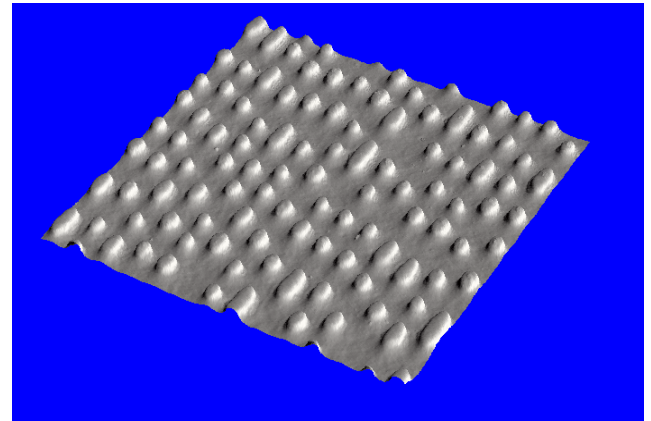
There are several approaches currently being taken to develop mastering systems that can generate pit dimensions compatible with next generation formats and beyond. Some of these are extensions of existing optical recording technology using shorter wavelengths down into to the deep ultraviolet regime of the spectrum. Other approaches leverage electron and ion beam technologies, which inherently are capable of high resolution but have to address a multitude of issues including mastering in

vacuum. Optical Disc Corporation's approach is to generate a cost effective and low risk technology that preserves the direct-read-after-write (DRAW) capability in order to assure a reliable and repeatable process and at the same time allows for a growth path for even higher densities.

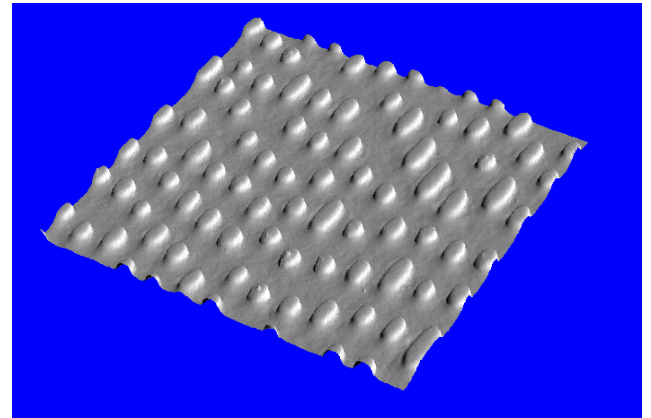
### Initial Results Using High Resolution Dye-Polymer

In order to address the requirement of higher resolution mastering and to come up with an effective mastering solution for next generation formats Optical Disc Corporation (ODC) has recently focused on development efforts to establish a new dye-polymer based recording technology. By materials and process optimization, enhanced mastering resolution has been achieved while enabling DRAW capability for precise process control. Initial results have been generated using this High Resolution Dye-Polymer™ in combination with a standard ODC DVD LaserWave™ laser beam recorder equipped with reduced track pitch capability.

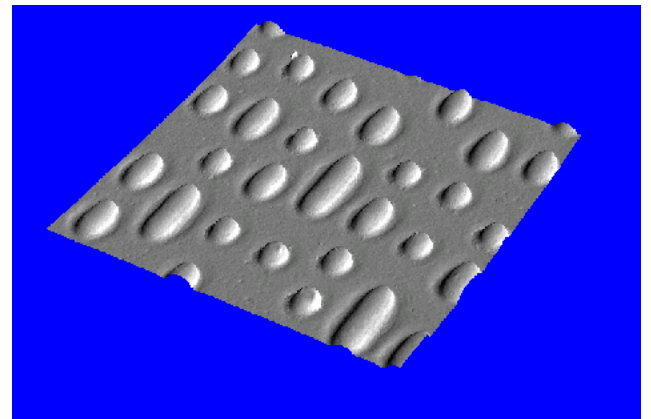
Figure 3 shows a comparison of three 5 μm x 5 μm sized atomic force microscope (AFM) images of stampers all generated from LaserWave recorded masters using a standard 488 nm argon (Ar) ion laser and 0.95 numerical aperture objective lens. Figure 3 (a) and (b) both correspond to high density recordings generated using High Resolution Dye-Polymer and EFM+ encoding whereas Figure 3 (c) corresponds to a DVD-5 format generated with standard ODC dye-polymer. From these images it is clear that the newly developed High Resolution Dye-Polymer is capable of generating significantly smaller pit dimensions than the standard dye-polymer. In fact the achievable pit widths are significantly smaller than the recording spot diameter at half intensity of about 260 nm. Pit (bump) widths of 170 nm with 80 nm depth (height) have been achieved, which is more than 30% smaller than the recording spot diameter. Figure 4 shows a detailed (inverted) radial AFM cross section of a long pit/bump of the 14.1 GB stamper superimposed on a cross section of the corresponding mother. The difference in width can be attributed to the non-zero tip radius of the AFM probe and the true geometry is given by the average of the two profiles. As is the case of standard ODC dye-polymer, High Resolution Dye-Polymer also generates smooth geometries on stampers that facilitate the release of the corresponding replica during the molding process and therefore minimize any staining (clouding) issues.



(a) 19.3 GB using High Resolution Dye-Polymer (360 nm track pitch, 200 nm min pit length).



(b) 14.1 GB using High Resolution Dye-Polymer (430 nm track pitch, 230 nm min pit length).



(c) 4.7 GB using standard ODC dye-polymer (740 nm track pitch, 400 nm min pit length).

Figure 3. AFM images of stampers generated from dye-polymer masters cut at a wavelength of 488 nm and a numerical aperture of 0.95.

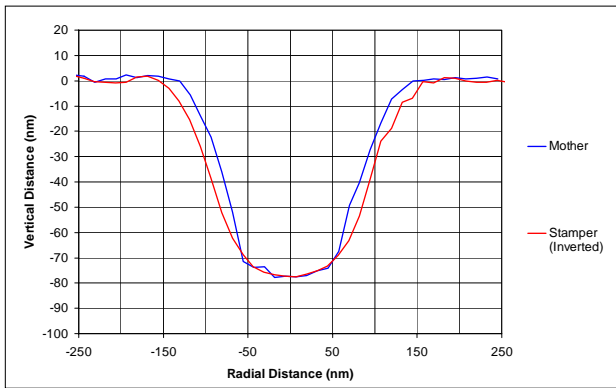


Figure 4. High Resolution Dye-Polymer pit geometry captured by an AFM.

Moreover, the pits are typically cut to between 50% and 80% of the dye-polymer thickness providing a means to independently tailor the high frequency response (“I<sub>3</sub>” playback signal) and asymmetry parameters of the replica through run length dependent pit depths and lengths.

Even though very small pit geometries can be achieved with High Resolution Dye-Polymer and a standard ODC LaserWave recorder, it is clear that even smaller geometries can be achieved by utilizing a reduced recording spot size. The achievable storage capacities/densities can be projected based on the obtained pit width of 170 nm generated with the 488 nm wavelength and the 0.95 numerical aperture (corresponding to a 260 nm spot diameter). Table 1 summarizes these projections again under the assumption that the capacities are based on the DVD format and margins. Capacities are given for krypton (Kr) ion laser lines in the visible blue (413 nm) and ultraviolet (351 nm) as well as for the frequency doubled 514 nm argon ion wavelength of 257 nm in the deep ultraviolet regime of the spectrum. At the ultraviolet wavelength of 351 nm it

Wavelength	Source	NA	Capacity
488	Ar-Ion	0.95	13 GB
413	Kr-Ion	0.95	18 GB
351	Kr-Ion	0.95	25 GB
351	Kr-Ion / SIL	1.3	47 GB
257	Ar-Ion Doubled	0.95	47 GB
257	Ar-Ion Doubled / SIL	1.3	88 GB

Table 1. Projected capacities (based on the DVD format and margins.) for High Resolution Dye-Polymer mastering.

is therefore possible based on these projections to achieve five times the DVD capacity/density with preserved margins using standard objective lens technology. Employing near field optics by means of a solid immersion lens (SIL) and/or deep ultraviolet wavelengths can achieve even higher densities beyond what is required for next generation blue/violet semiconductor laser based players.

## Conclusions and Further Developments

With the new blue/violet semiconductor lasers and based on the DVD format and margins, 14 GB single layer optical discs can be read back reliably with only a moderate increase in player numerical aperture and minor change in design and manufacturing of the disc substrate. Near four times the DVD capacity required by high definition digital video applications could be achieved with a relatively large increase in player numerical aperture and incorporation of new player and disc technology. As always, however, the player and disc manufacturing costs, the blessings of content providers, as well as the acceptance of consumers will determine the success of these future formats.

Using a new High Resolution Dye-Polymer developed by ODC, mastering densities are projected to support the approximately five times DVD capacity without employing deep ultraviolet, particle beams, or near field optics technology. This new High Resolution Dye-Polymer also allows for DRAW capability and generates well-defined and smooth pits. Among the further development efforts continuing at ODC are the integration of a short wavelength DRAW laser to allow for closed-loop control of the record beam as well as the investigation and verification of projected performance of High Resolution Dye-Polymer using shorter wavelength record lasers.

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