SCRATCH ADHESION TESTING
OF DISC COATINGS

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INTRODUCTION

Compact disc (CD) and Blu-ray disc (BD) are optical discs used to store music, video and data by writing data as pits in a reflective layer. The plastic disc is composed of polycarbonate and a thin metal layer. Optical discs are susceptible to damage during handling and from environmental exposure.

With the same physical dimension, the BD possesses a substantially higher storing capacity of 25 GB per layer, compared to 700 MB for CD. Such an increased capacity for BD was achieve by the employment of advanced techniques such as applying a blue-violet laser, increasing the numerical aperture of objective lens, making the optical beam passing a thinner cover layer, etc. This leads to different layer architecture between BD and CD as displayed in Fig. 1[i]. BD has a much thinner cover layer of ~0.1 mm, compared to ~1.1 mm for CD. Since the BD data layer is closer to the clear side of the disc, it is more vulnerable to scratches. Therefore, the testing of scratch resistance is required by the Blu-ray Disc specification, and hard coating technology is developed to produce strong scratch-protection coatings. A reliable and repeatable technique to quantitatively assess and compare the scratch resistance of different coatings becomes vital for the R&D and quality control of the protective optical coatings.

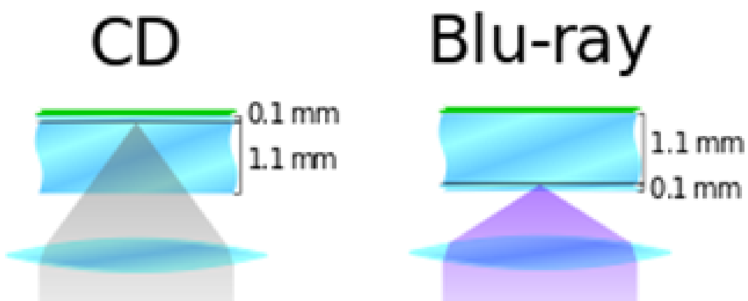


Fig. 1: Comparison of CD and BD layer architecture.

MEASUREMENT OBJECTIVE

In this study, instrumented scratch testing is used to assess the failure modes of the top layers of CD and BD. This test allows users to quantitatively compare the scratch resistance of different protective coatings.

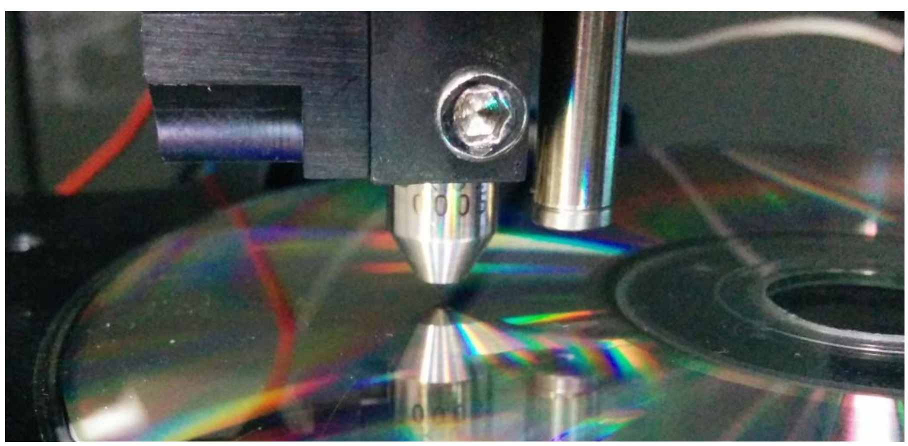


Fig. 2: Scratch test setup.

TEST PARAMETERS

The Nanovea Mechanical Tester was used to perform the scratch tests on the CD and BD coatings using the same test parameters as summarized in Table 1. Since the data layer is closer to the label side of CD and the clear side of BD which have a comparable thickness of 0.1 mm, it is more vulnerable to scratches on these sides. As a result, the scratch resistance of the label side of CD and the clear side of BD is compared in this study. For detailed coating thickness measurement of CD and BD cover layers refer to the Application Note "Transparent Coating Analysis Using Non-Contact Optical Profilometer".

Loading mode	Progressive (linear)
Initial Load	0.1 N
Final Load	20 N
Loading Rate	20 N/min
Scratch Speed	8 mm/min
Scratch Length	8 mm
Indenter material	Diamond
Indenter Type	Sphero-Conical
Indenter Radius	200 µm

Table 1: Test parameters of the scratch tests on CD and BD.

RESULTS AND DISCUSSION

Fig. 3 shows the evolution of Coefficient of Friction (COF) and Depth of CD and BD as a function of the normal load of the stylus during the scratch tests. It can be observed that the stylus penetrates substantially faster and deeper into CD than BD. The final depth of the CD and BD at a load of 20 N is ~290 and ~130 µm, respectively. The CD has a higher COF than BD throughout the scratch test.

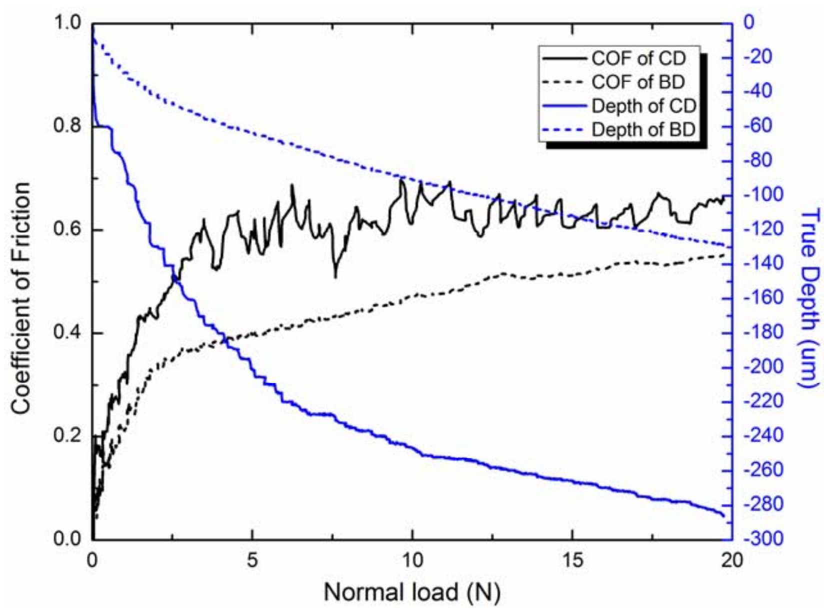
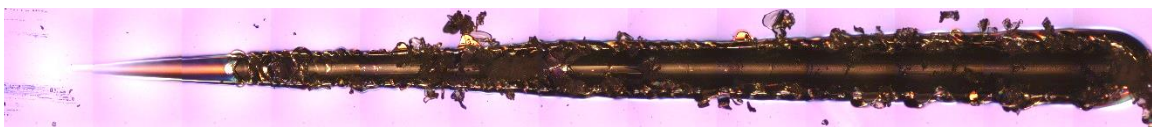


Fig. 3: Evolution of COF and Depth of CD and BD during the scratch tests.

Fig. 4 compares the panorama of the scratch track on CD and BD, and Fig. 5 displays the cohesive or adhesive failures appearing at certain critical loads, L_c, which is defined as the lowest load at which a recognizable failure occurs. The CD exhibits much more severe damages in the coating compared to BD. The indenter initially creates plastic deformation and leaves permanent marks on the coating at a load of 0.01 and 0.86 N, respectively, for CD and BD. As the load progressively increases to 3.08 N, delamination of the coating starts to take place on the CD surface. The stylus reaches the recording layer and creates permanent damage to the data. This is correlated with the fast increase of the COF before the normal load of 3.08 N and the noticeable oscillation of the COF thereafter. The coating has been completed removed at the end of the scratch test where the stylus penetrates to a depth of 0.286 mm. In comparison, BD coating shows the first sign of cohesive crack at a load of 5.91 N, followed by periodical occurrence of such cracks. However, the coating maintains its adhesion to the substrate underneath throughout the test. It exhibits no sign of delamination till the end of the test, where the load of 20 N creates a penetration depth of 0.128 mm.

(a) Panorama of the scratch track on CD:



(b) Panorama of the scratch track on BD:

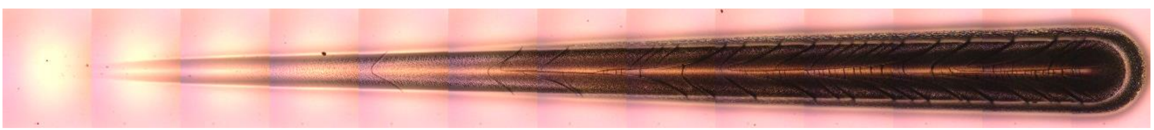
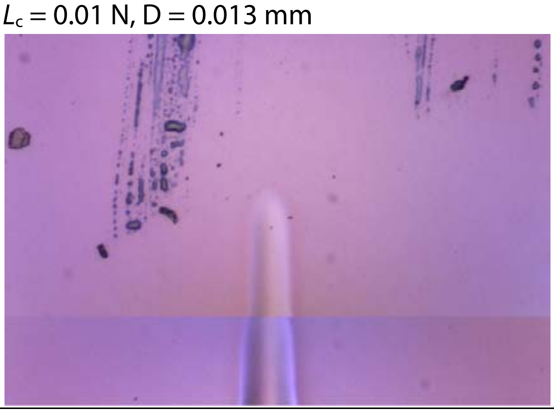
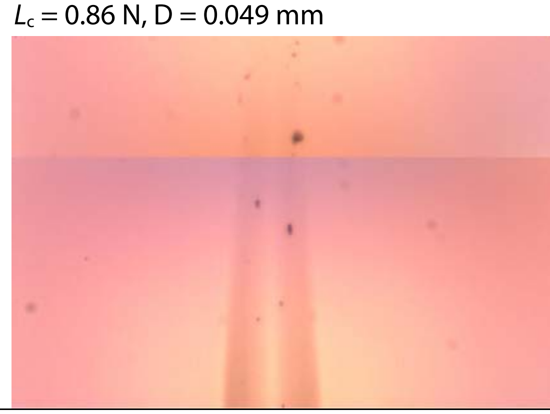


Fig. 4: Panorama of the scratch tracks on CD and BD.

(a) CD:	(b) BD:
L_c = 0.01 N, D = 0.013 mm	L_c = 0.86 N, D = 0.049 mm
	

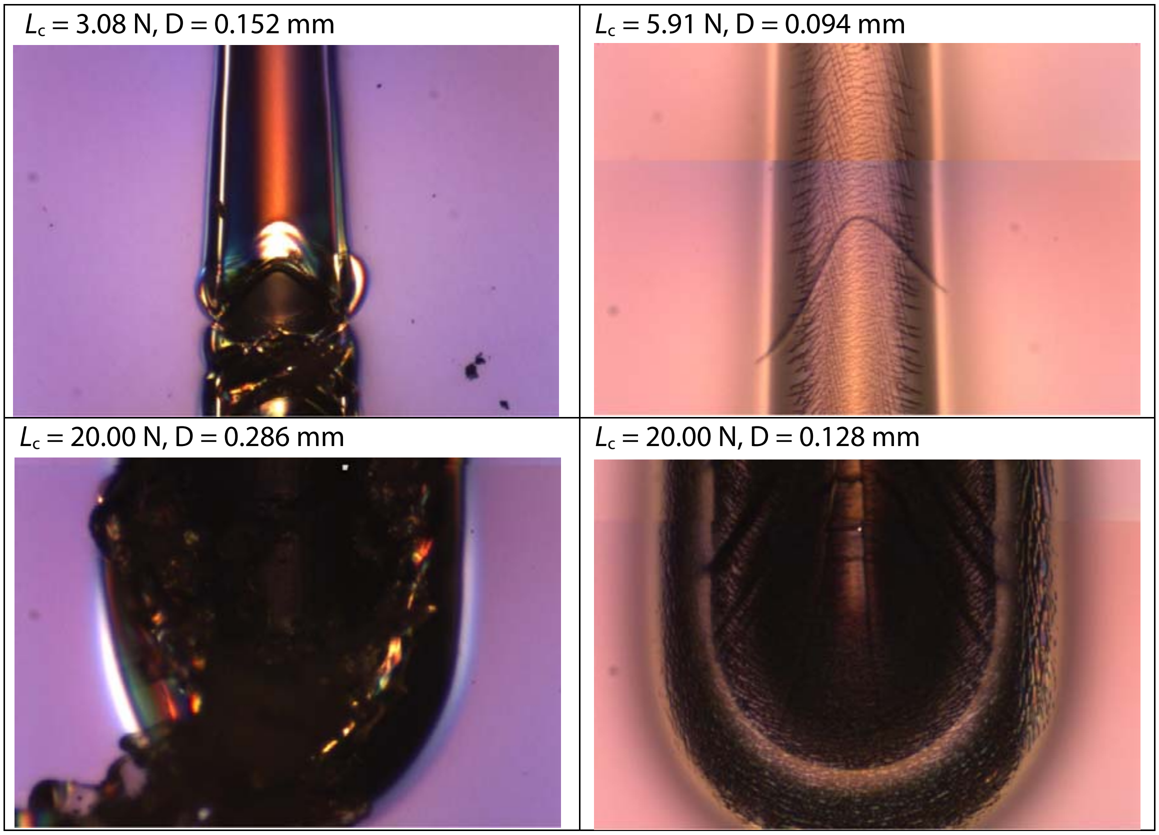


Fig. 5: Failures occurring at different critical loads.

Such quantitative analysis of the COF, penetration depth and critical loads of the scratch track provides users a reliable and repeatable tool to assess the scratch resistance, as well as cohesive and adhesive strength of the protective coatings.

CONCLUSION:

In conclusion, the Nanovea Mechanical Tester measures the scratch resistance in a controlled and closely monitored fashion and use critical loads as a quantitative value for comparing the cohesive and adhesion strength in different protective coatings. The BD cover layer in this study shows a significantly enhanced scratch resistance compared to CD.

The Nano, Micro or Macro modules of the Nanovea Mechanical Tester all include ISO and ASTM compliant indentation, scratch and wear tester modes, providing the widest and most user friendly range of testing available on a single module. Nanovea's unmatched range is an ideal solution for determining the full range of mechanical properties of thin or thick, soft or hard coatings, films and substrates, including hardness, Young's modulus, fracture toughness, adhesion, wear resistance and many others.

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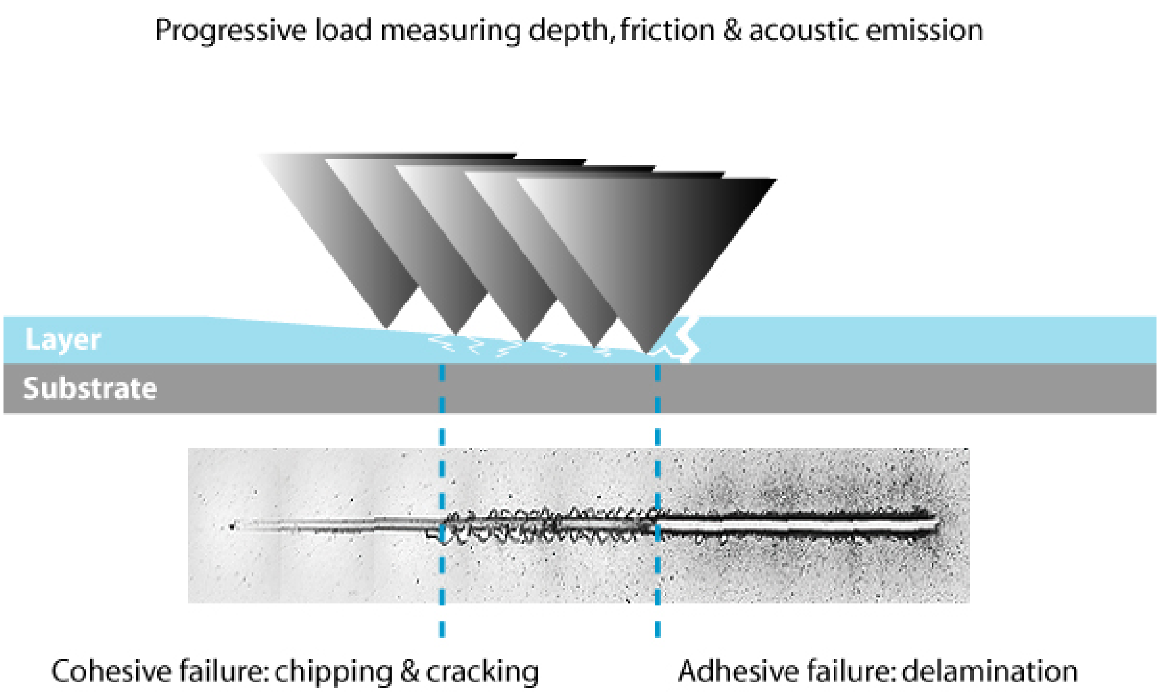
APPENDIX: SCRATCH TEST PRINCIPLE

The scratch testing method is a comparative test in which critical loads at which failures appear in the samples are used to evaluate the relative cohesive or adhesive properties of a coating or bulk material. During the test, scratches are made on the sample with a sphero-conical stylus (generally Rockwell C diamond, tip radius ranging from 20 to 200μm) which is drawn at a constant speed across the sample, under a constant load, or, more commonly, a progressive load with a fixed loading rate.

When performing a progressive load test, the critical load (L_c) is defined as the smallest load at which a recognizable failure occurs. The driving forces for coating damage in the scratch test are a combination of elastic-plastic indentation stresses, frictional stresses and the residual internal stresses. In the lower load regime, these stresses generally result in conformal or tensile cracking of the coating which still remains fully adherent. The onset of these phenomena defines a first critical load. In the higher load regime, one defines another critical load which corresponds to the onset of coating detachment from the substrate by spalling, buckling or chipping.



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[i] http://en.wikipedia.org/wiki/Blu-ray_Disc