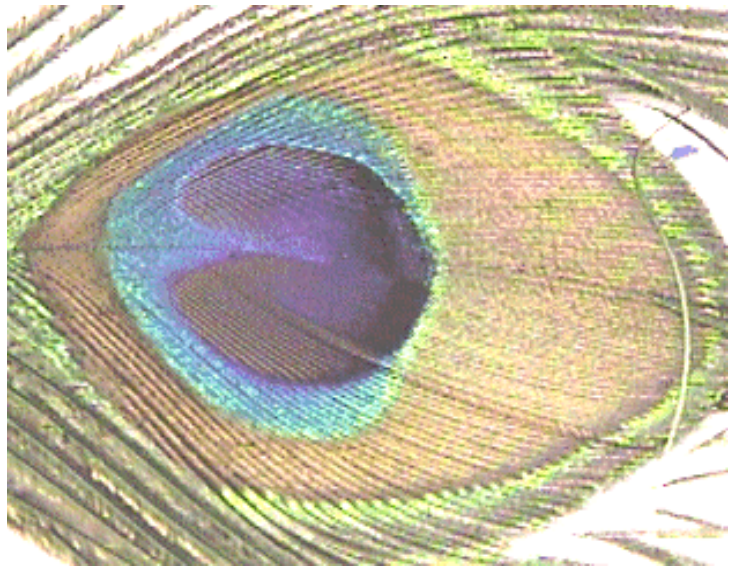
Cholesteric Liquid Crystal Polymer Pigments Overview

High Performance Pigment Conference
January 23, 2002



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CHELIX

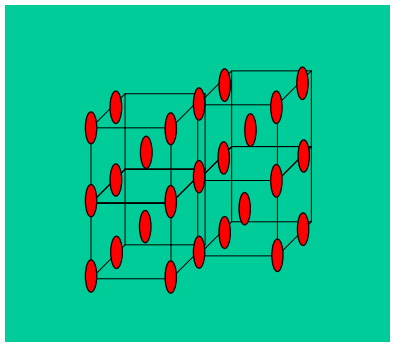
Transforming Light Through Chemistry

Agenda

- Cholesterics Liquid Crystals (CLC)
- Optical Properties of Special Effect Pigments
- Manufacturing of CLC Pigments
- CLC's Advantages and Market Opportunity
- Next Generation Developments

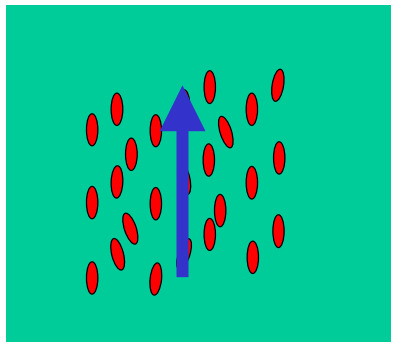
Basics of Liquid Crystals

Crystalline



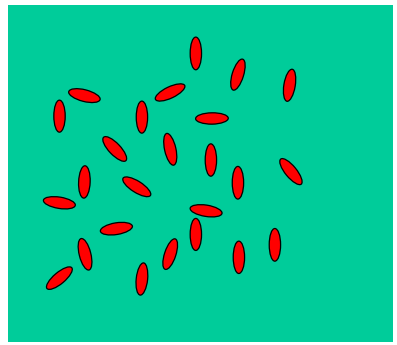
3D orientation
Rigid Structure

Liquid Crystal



Ordered position
Glassy flow

Liquid

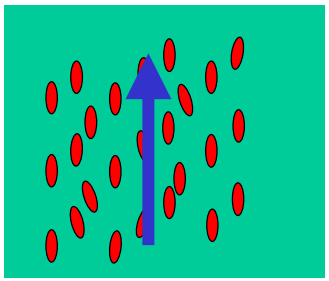


No Order
Fluid Flow

- Two primary phases of Liquid Crystals, Smectic and Nematic
- Smectic (Greek for grease) LCs have alignment along the short axis
- Nematic (Greek for string) LCs have alignment along the long axis
- Cholesteric (CLC) or chiral nematic is a subset of nematic LCs

Basic Technology

Nematic LC

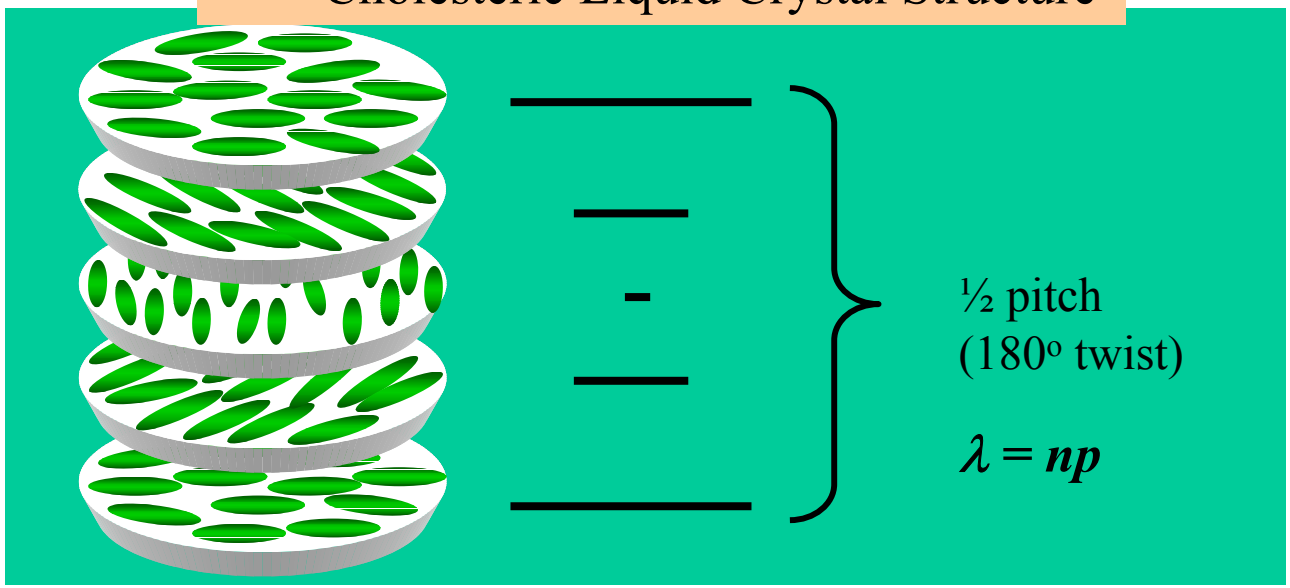


\+

Chiral Dopant
(sterol esters,
cyanobiphenyls)

=

Cholesteric Liquid Crystal Structure



Note: n is the index of refraction, and p equal pitch (full twist, 360°)

CHELIX = Cholesteric + Helix

Key Properties of CLCs

To enable a good special effect pigment from cholesteric liquid crystal technology, several properties need modification.

Cholesteric Liquid Crystals:

- Periodic structure (enables color travel)
- Thermochromic (color change with temperature)
- Alignment required
- Highly aromatic in nature

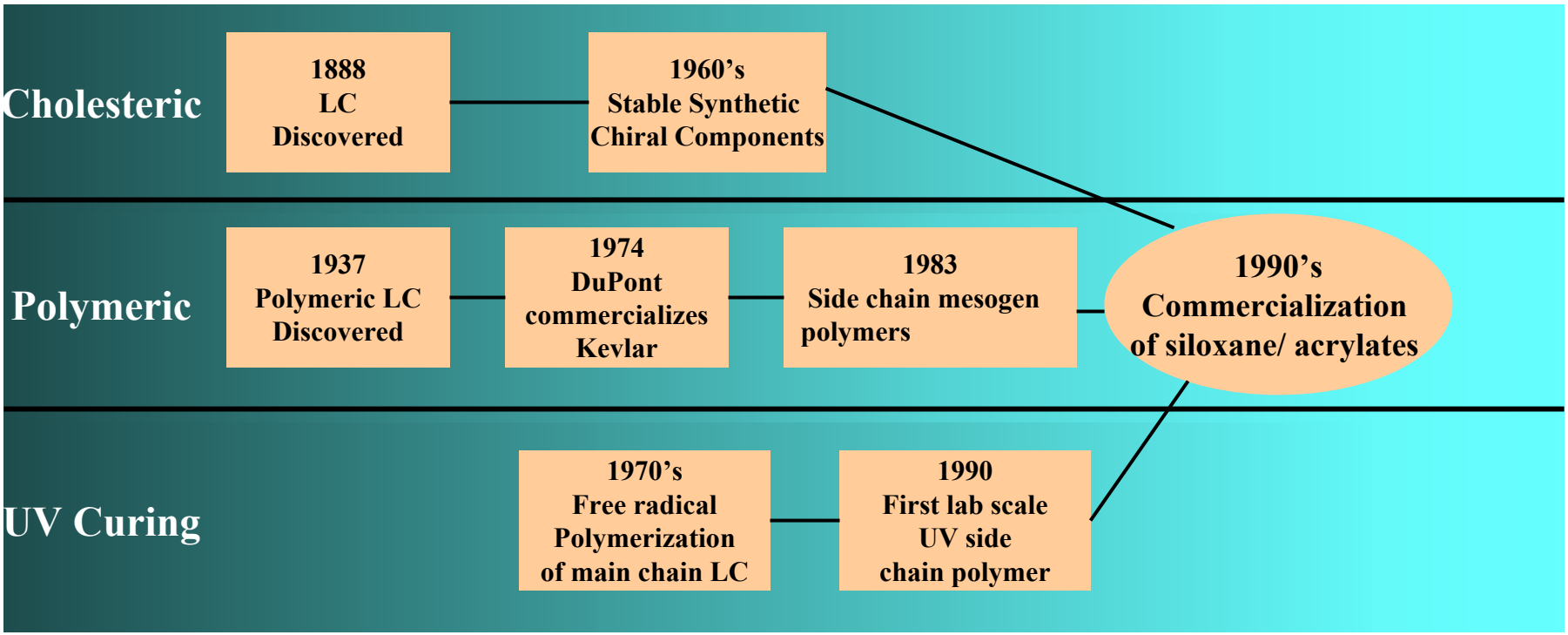
Pigment Application needs:

- Temperature Insensitive (Color Fixed)
- Fairly Durable Properties (Tg, temperature, chemical resistance)
- Good processing (ease of manufacture)

Non-Thermally Polymerizable Cholesterics based on flexible backbones

History of CLCs

CLC pigments were enabled by the convergence of cholesteric, polymeric and UV curative liquid crystal technologies

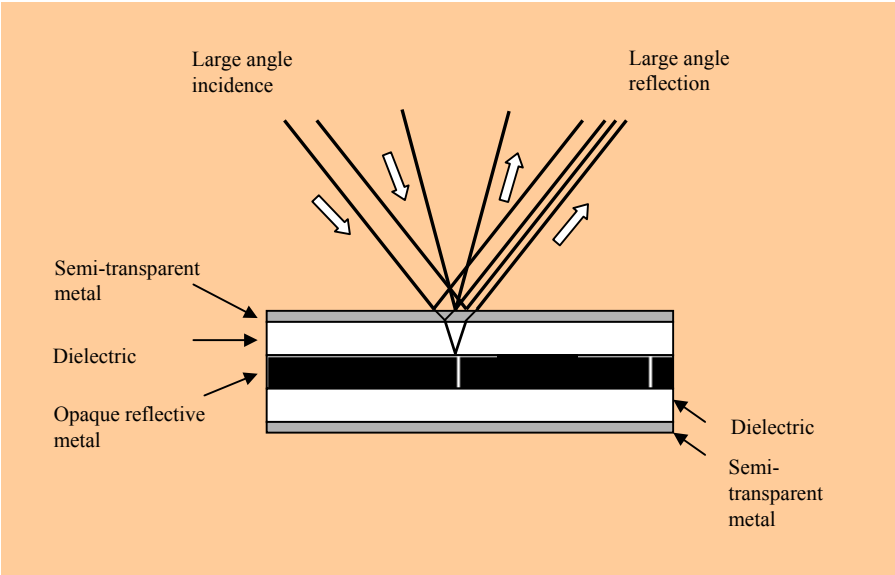


Chelix's parent, Reveo, was the first to patent CLC use in pigments

Optical Properties of Color Travel Pigments

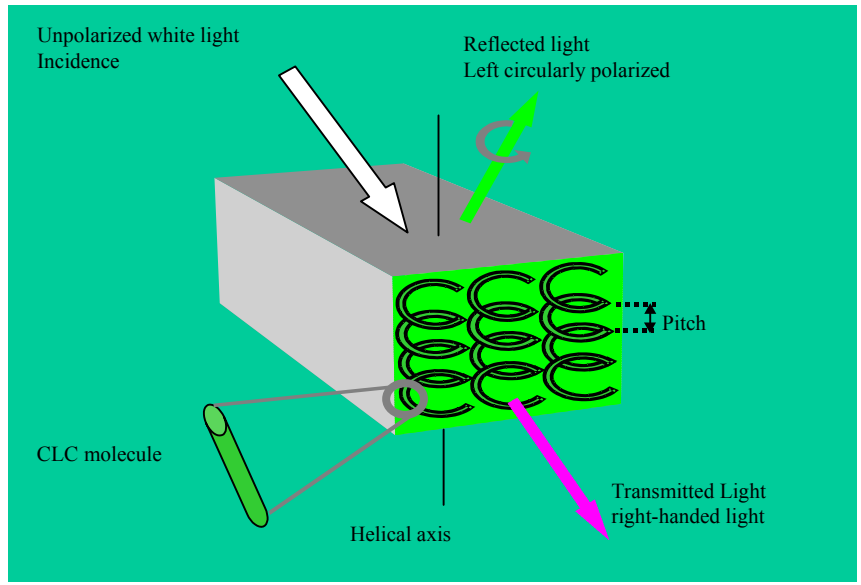
Unlike metal interference systems, CLCs develop color reflection through one single layer

Metal Interference Stack



Color Change through multiple layers periodic structure

CLC Technology

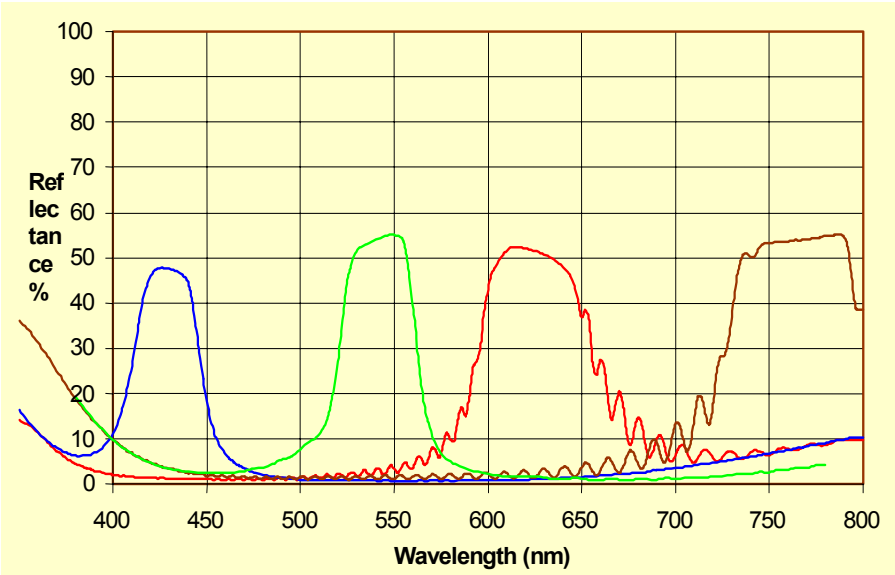


Color Change through single layer reflective periodic structure

CLC Design Flexibility

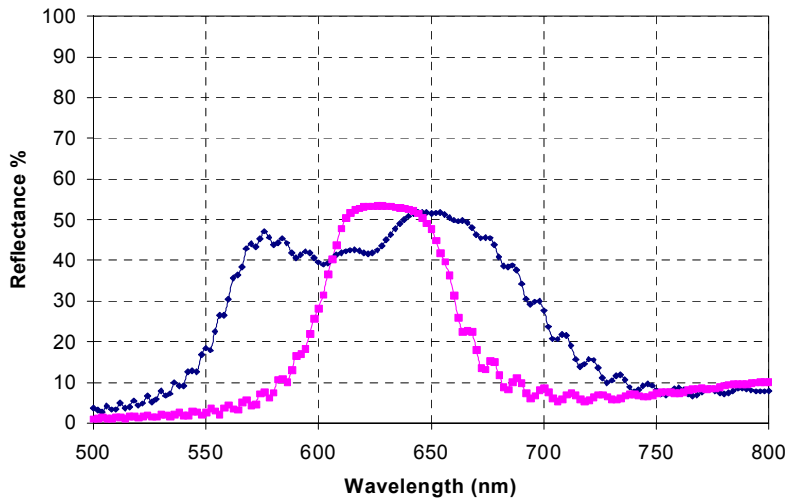
The wavelength that CLC reflects is dependent on formulation and process

Wavelength Modification



From deep blue to near IR

Bandwidth Modification

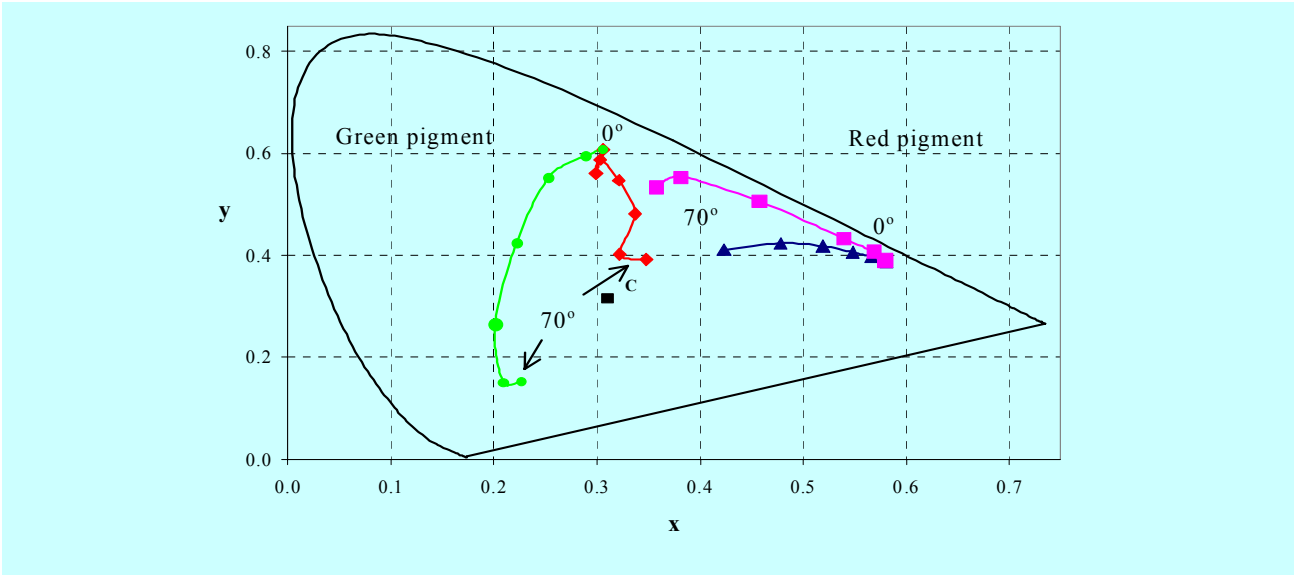


Before and after broadening process

CLC Pigment Color Travel

CLC pigments have excellent blue-shifting color travel.

CLC Color Travel



Squared line: red pigment with specula reflection; triangle line: red pigment with light source fixed at 0°.

Round-dotted line: green pigment with specula reflection; diamond line: green pigment with light source fixed at 0°

Note: Chelix Measurements on Siloxane based pigments

Circularly Polarized

Light reflected from a CLC is circularly polarized; this effect can be used in security and machine read applications.

Same polarization

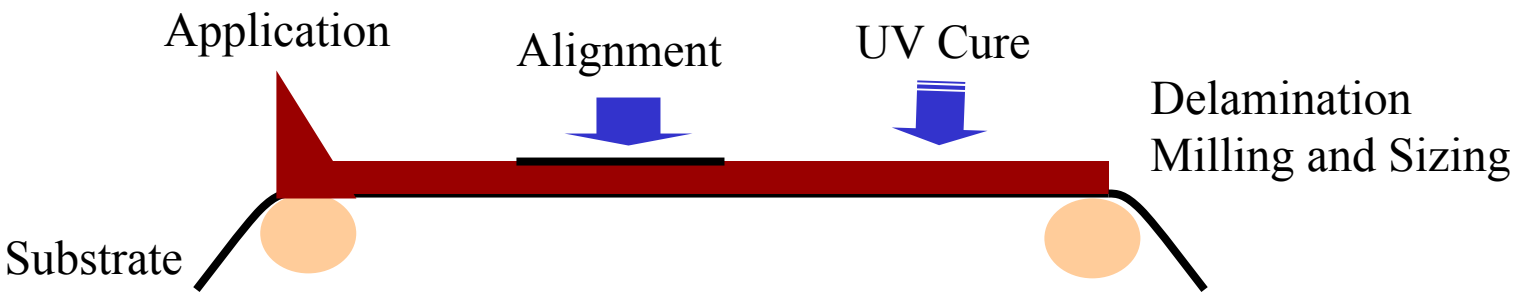
Opposite polarization*

Note*: filter is the opposite handedness as CLC pigment

CLC Process

Currently Wacker is the only commercial producer of CLC pigments using a modified coating process. High speed roll to roll processes are possible.

Estimated Current Process*



New Approach

- New process similar to high speed converting lines
- One side alignment possible
- Delamination and collection on separate machines

*Wacker HPP 2000 Presentation, Wacker patents

CLC Technical Advantages

CLCs have both product and process advantages over metal stack systems…..

	Advantages	Disadvantages
Product	•Circularly polarized •Low density •Inert, organic •Reflective technology	•Transparent •Light fastness •Large particle size
Processing	•High speed roll to roll processing – high throughput with small capt investment •Lower process costs	•Raw material supply constricted

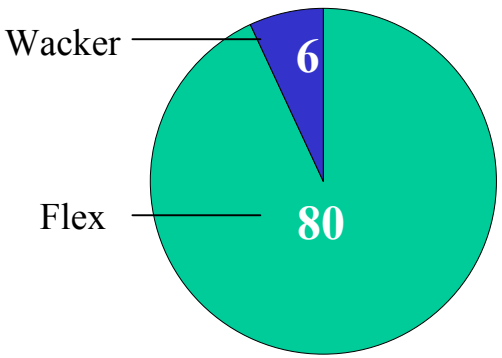
… but CLC pigments application issues limit market reach

Color Travel Pigment Market Opportunity

We estimate by 2007, the market for color travel pigments should exceed 300 tons, split between security and decorative applications.

2000 Color Travel Pigment Volume

(estimated in metric Tons)

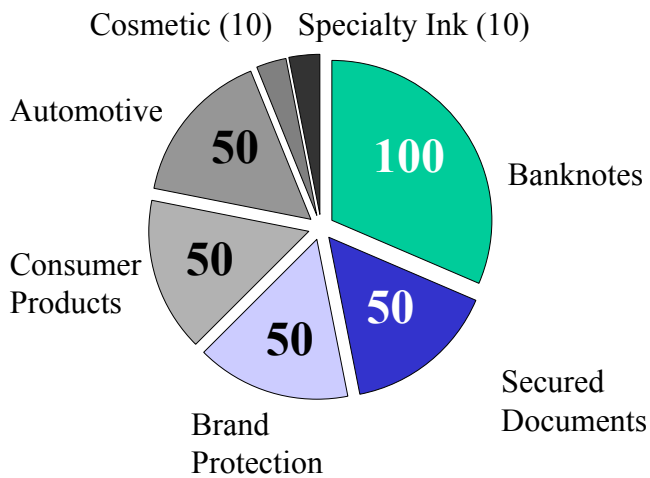


Note: Does not include volumes by BASF, Merck
Note: Flex Products volume estimated from 1999 results

25% CAGR

2007 Color Travel Estimate Volume

(estimated in metric Tons)



Note: Chelix estimates from user interviews
Note: Banknote estimates from various government, consulting sources

Next Generation Developments

- **“Thin” CLC pigments**
- **High process speeds – 100 ft/min**
- **Multilayer CLC systems**
- **Doping the CLC pigment**
- **Smart Pigments (controlled shape)**

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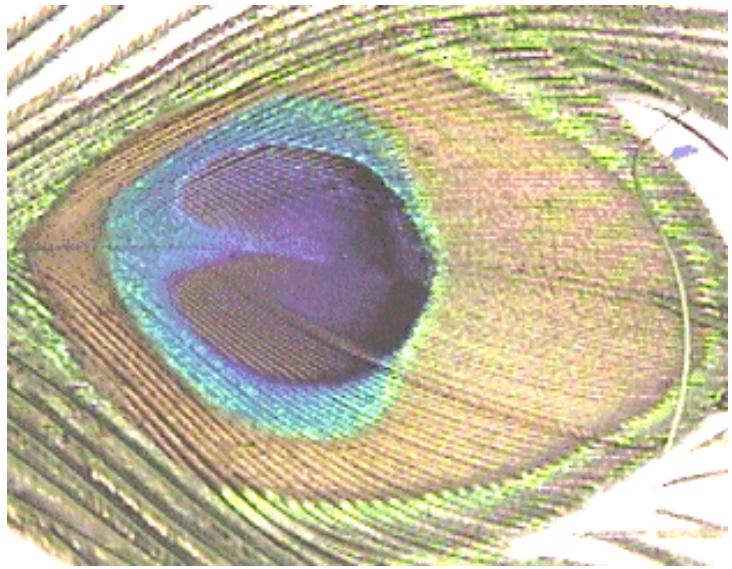

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