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# HIGH PERFORMANCE SUBSTRATES FOR THIN FILM APPLICATIONS

## HIGH PERFORMANCE SUBSTRATES FOR THIN FILM APPLICATIONS: A contemporary survey of materials

A wide array of substrate materials suitable for thin-film applications will be reviewed. This will include the standard thin-film hybrid 99% + alumina tape-cast ceramics as well as many less common hot pressed ceramics, glasses, glass-ceramics, single crystals, metals, polymers, etc, useful in specialized high performance applications.

The main characteristics pertinent to the thin film technologist will be discussed, viz the surface finishes attainable, the mechanical, machining and wear properties, the physical, chemical electrical and thin film adhesion qualities. These substrate materials have applications in hybrids, very high density interconnect packaging, microwave, high power devices, magnetic thin film heads and many other specialized sensors or devices.

## THIN FILM SUBSTRATES
## A TECHNICAL OVERVIEW

THIN FILM SUBSTRATE CRITERIA:

* SUBSTRATE MATERIAL
* SURFACE FINISHING TECHNIQUES
* TESTING SUBSTRATE PARAMETERS
* SUBSTRATE RELATED SUBJECTS:
  ADHESION
  METALLIZING

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## CERAMICS

MANUFACTURING PROCESSES:

* TAPE CASTED
  PARTICLES IN POLYMERIC BINDER
  SLURRY + DOCTOR BLADE

* DRY PRESSED
  ROOM TEMP, LOW PRESSURE
  LITTLE POLYMERIC BINDER

* HIPPED
  NO BINDER
  HEAT + PRESSURE (gas in vessel)
  to 1400$^{o}$C 30,000 psi

* HOT-PRESSING
  NO BINDER
  MECHANICAL PRESSURE
  to 1800$^{o}$C 80,000 psi

## CRITERIA TO CHOOSE A SUBSTRATE MATERIAL

* MECHANICAL
  STRENGTH
  POROSITY
  SURFACE FINISH
  EASE OF MACHINING

* THERMAL
  CONDUCTIVITY
  CAPACITY
  EXPANSION COEFFICIENT

* CHEMICAL
  STABILITY
  SURFACE STATE (ADHESION)
  THIN FILM COMPATIBILITY

* ELECTRICAL
  BULK RESISTIVITY
  DIELECTRIC CONSTANT
  DIELECTRIC BREAKDOWN
  DISSIPATION FACTOR

## CERAMICS

| | |
|---|---|
| * ALUMINAS | 99.5%+ $Al_2O_3$ |
| | LUCALOX (Polycrystalline) |
| | $Al_2O_3$-TiC |
| * BERYLLIAS | 99.5%+ BeO |
| * CARBIDES | $B_4C$, SiC, TiC |
| * NITRIDES | AlN, $Si_3N_4$, Sialon |
| * TITANIAS | $BaTiO_3$, $CaTiO_3$, $TiO_2$ |
| * ZIRCONIAS | $ZrO_2$ |
| * FERRITES | Zr, Ni-Zr, Mn-Zn |
| * BORIDES | $TiB_2$ |

## MATERIAL PROPERTIES
(HOT PRESSED)

| MATERIALS | FLEXURAL STRENGTH ($Kg\ cm^{-2}$) |
|---|---|
| * $BaTiO_3$ | 1250 |
| * $CaTiO_3$ | 1500 |
| * BeO | 1750 |
| * $Al_2O_3$ | 3200 |
| * AlN | 4000 |
| * SiC | 4500 |
| * $Al_2O_3$-TiC | 6000 |
| * $Al_2O_3$ (Sapphire) | 7000 |
| * $ZrO_2$ | 8500 |

## HARDNESS (Knoops Indentation Test)

| MATERIAL | $Kg\ mm^{-2}$ (@ 100g load) |
|---|---|
| * C (Graphite) | 200 |
| * PZT | 400 |
| * Fotoceram | 500 |
| * Quartz | 570 |
| * Mn-Zn (Ferrite) | 650 |
| * Zn (Ferrite) | 700 |
| * Ni-Zn (Ferrite) | 750 |
| * $CaTiO_3$ | 800 |
| * $SiO_2$ | 800 |
| * $BaTiO_3$ | 850 |
| * $ThO_2$ | 1000 |
| * AlN | 1200 |
| * BeO | 1200 |
| * $Al_2O_3$ | 1600 |
| * $Si_3N_4$ | 1850 |
| * $Al_2O_3$-TiC | 1850 |
| * $Al_2O_3$ (Hot Pressed) | 2000 |
| * $ZrO_2$ | 2000 |
| * $B_4C$ | 3000 |

## DIELECTRIC PROPERTIES

| MATERIAL | CONSTANT (1 MHz) | LOSS TANGENT ($10^{-4}$) |
|---|---|---|
| Polyimide | 3.5-3.8 | 20 |
| Quartz | 3.7 | 1 |
| BN | 4.1 | 13 |
| Glass | 4.5-6.0 | 20 |
| Fotoceram | 6.0 | 40 |
| BeO | 6.5 | 1 |
| $Si_3N_4$ | 7-10 | 3 |
| $Al_2O_3$ (99.5%+) | 9.0 | 1.5 |
| AlN | 9.1 | 71 |
| $Al_2O_3$ (Sapphire) | 9.3 | 1 |
| Si | 12 | 100 |
| GaAs | 13 | 16 |
| YIG | 14 | 2 |
| $CaTiO_3$ | 25 (5 GHz) | 5 |
| $BaTiO_3$ | 37 (5 GHz) | 5 |
| $TiO_2$ | 100 (5 GHz) | 4 |

## THERMAL CONDUCTIVITY

| MATERIAL | W/m C |
|---|---|
| * Quartz | 1.4 |
| * Glass | 1.2-2.0 |
| * $ZrO_2$ | 2.0 |
| * Fotoceram | 2.5 |
| * $BaTiO_3$ | 3.6 |
| * Zn (Ferrite) | 4.0 |
| * Ni-Zn (Ferrite) | 4.0 |
| * Mn-Zn (Ferrite) | 4.0 |
| * $CaTiO_3$ | 5.2 |
| * $ThO_2$ | 12.0 |
| * $Al_2O_3$-TiC | 16.0 |
| * $Al_2O_3$ | 17.0 |
| * $Si_3N_4$ | 32.0 |
| * $B_4C$ | 32.0 |
| * BN | 44.0 |
| * SiC-Si | 50.0 |
| * $TiB_2$ | 70.0 |
| * AlN | 125.0 |
| * Al | 140.0 |
| * BeO | 240.0 |
| * SiC | 270.0 |
| * C (Graphite) | 800.0 |
| * C (Diamond) | 1000.0 |

## THERMAL COEFFICIENT OF EXPANSION

| MATERIAL | ppm/C |
|---|---|
| * Zerodur | -0.02 |
| * Quartz | 0.55 |
| * Glass | 1.2 |
| * $Si_3N_4$ | 3.0 |
| * C (Graphite) | 3.2 |
| * Si | 3.4 |
| * AlN | 4.8 |
| * SiC | 5.1 |
| * $Al_2O_3$ (Sapphire) | 5.6 |
| * $Al_2O_3$ (Ceramic) | 6.5-8.0 |
| * $Al_2O_3$-TiC | 7.8 |
| * $TiB_2$ | 8.2 |
| * Zn (Ferrite) | 8.5 |
| * BeO | 8.0-9.0 |
| * Ni-Zn (Ferrite) | 9.1 |
| * $ThO_2$ | 9.3 |
| * $BaTiO_3$ | 9.6 |
| * Fotoceram | 10.0 |
| * $ZrO_2$ | 10.0 |
| * $CaTiO_3$ | 11.5 |
| * Mn-Zn (Ferrite) | 12.1 |
| * Cu | 18.0 |
| * Al | 23.0 |

## BULK RESISTIVITY

| MATERIAL | OHMS-cm |
|---|---|
| * Al | $2.7 \times 10^{-6}$ |
| * Cu | $1.7 \times 10^{-6}$ |
| * $TiB_2$ | $1.0 \times 10^{-5}$ |
| * C (Graphite) | $1.0 \times 10^{-4}$ |
| * Mn-Zn (Ferrite) | 1 |
| * SiC | 5 |
| * $B_4C$ | 5 |
| * $Al_2O_3$-TiC | 10 |
| * Zn (Ferrite) | $>10^3$ |
| * Ni-Fe (Ferrite) | $>10^6$ |
| * Quartz | $>10^9$ |
| * $ThO_2$ | $>10^{10}$ |
| * $ZrO_2$ | $>10^{10}$ |
| * AlN | $>10^{11}$ |
| * $Al_2O_3$ | $>10^{14}$ |
| * BeO | $>10^{14}$ |
| * $BaTiO_3$ | $>10^{14}$ |
| * $CaTiO_3$ | $>10^{14}$ |
| * Polyimide | $>10^{14}$ |

## SUBSTRATE MEASUREMENTS

* CHEMICAL
  ESCA, AUGER, ETC.

* DIELECTRIC CONSTANT
  BRIDGE, PHASE-METER, LOCK-IN-AMP

* CONDUCTIVITY
  BRIDGE, 4 POINT PROBE, ELECTROMETER

* FLATNESS
  OPTICAL FLAT, AIR GAUGE, INTERFEROMETER

* CAMBER
  PARALLEL PLATES, INTERFEROMETER

* POROSITY, SCRATCHES, PITS & BURRS
  MICROSCOPE, SEM

* CRACK DETECTION
  DIES, VAPOR CONDENSATION

* SURFACE FINISH
  STYLUS PROFILOMETER, OPTICAL PROFILOMETER

* WEAR TEST
  SLIDING PIN ON DISC