9th Annual Meeting of KACG

and

3rd Japan-Korea Electronic Materials Growth Symposium

TITLE: "Aluminium Nitride Technology - a review of problems and potential"

AUTHOR: Peter M.Dryburgh.

AFFILIATION: Department of Electrical Engineering
The University of Edinburgh
The King's Buildings
Edinburgh EH9 3JL
Scotland, UK

ABSTRACT

This review is presented under the following headings:

1.Introduction
1.1 Brief review of the properties of AlN
1.2 Historical survey of work on ceramic and single crystal AlN

2.Thermochemical background

3. Crystal growth

4. Doping

5. Potential applications and future work

The known properties of AlN which make it of interest for various applications are discussed briefly. The properties include chemical stability, crystal structure and lattice constants, refractive indices and other optical properties, dielectric constant, surface acoustic wave velocity and thermal conductivity.

The history of work on single crystals, thin films and ceramics are outlined and the thermochemistry of AlN reviewed together with some of the relevant properties of aluminium and nitrogen; the problems encountered in growing crystals of AlN are shown to arise directly from these thermochemical relationships.

Methods have been reported in the literature for growing AlN crystals from melts,

solution and vapour and these methods are compared critically. It is proposed that the only practicable approach to the growth of AlN is by vapour phase methods.

All vapour based procedures share the same problems:

- the difficulty of preventing contamination by oxygen & carbon
- the high bond energy of molecular nitrogen
- the refractory nature of AlN (melting point ~ 3073K at 100ats.)
- the high reactivity of Al at high temperatures

It is shown that the growth of epitactic layers and polycrystalline layers present additional problems:

- chemical incompatibility of substrates
- crystallographic mismatch of substrates
- thermal mismatch of substrates

The result of all these problems is that there is no good substrate material for the growth of AlN layers.

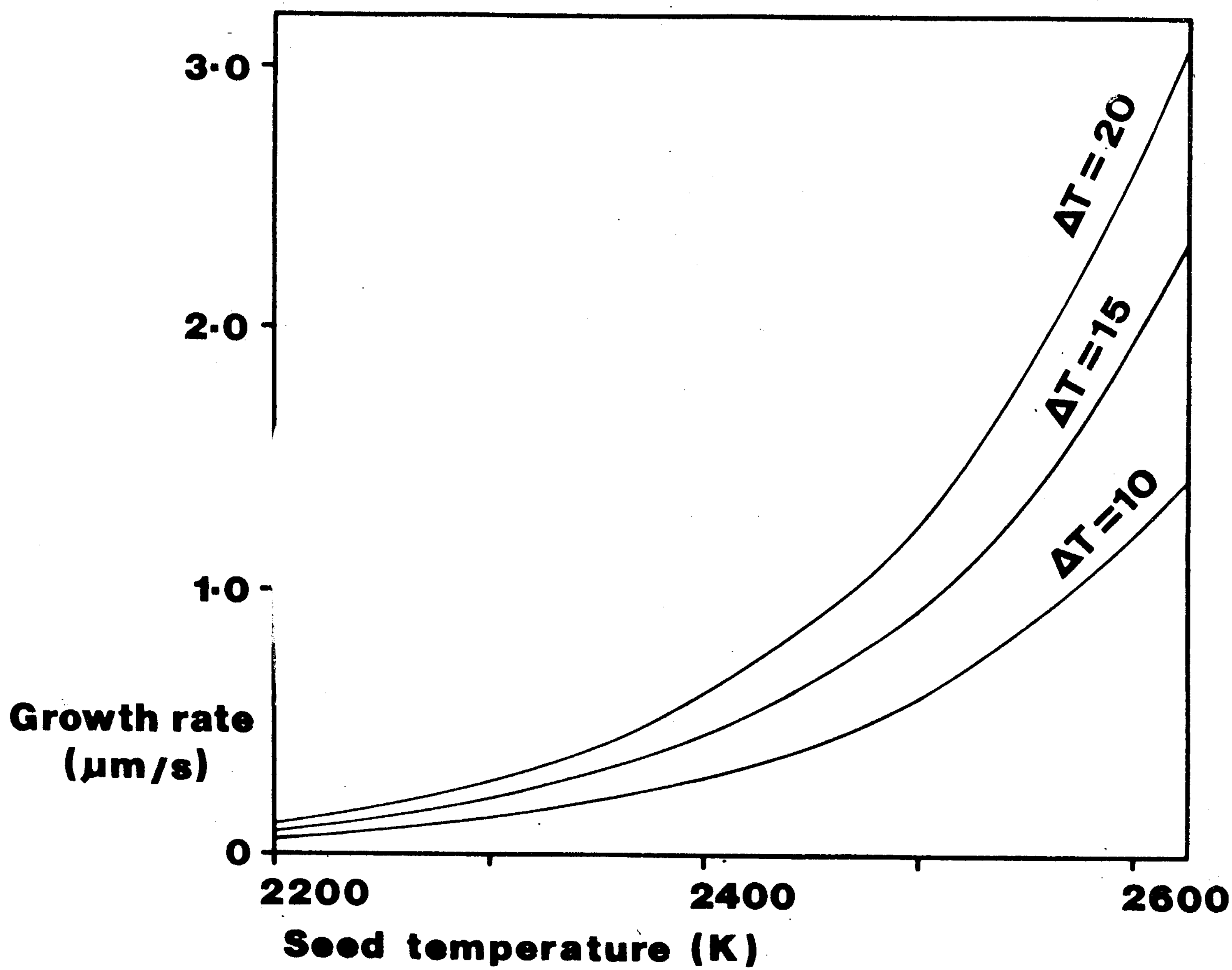
Organometallic precursors which contain an Al-N bond have been used recently to deposit AlN layers but organometallic precursors have the disadvantage of giving significant carbon contamination.

It is concluded that progress in the application of AlN to optical and electronic devices will be made only if considerable effort is devoted to the growth of large, pure (and particularly, oxygen-free) crystals. Progress in applications of epi-layers and ceramic AlN would almost certainly be assisted also by the availability of more reliable data on the pure material.

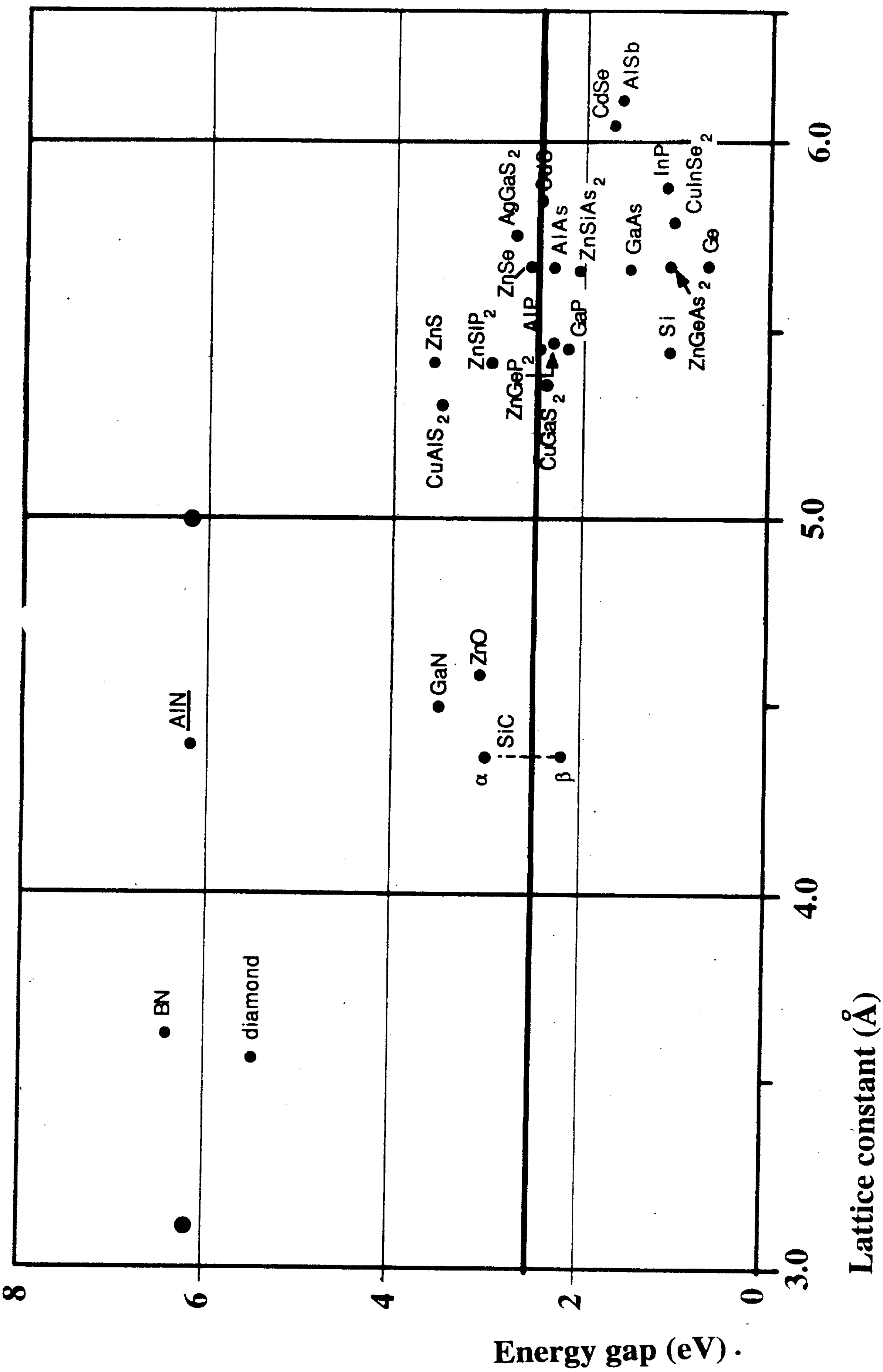
The essential features of any stategy for the growth of AlN from the vapour are outlined and discussed.

	PROPERTY	APPLICATIONS
OPTICAL	high refractive index high dispersion	prisms, gems
OPTICAL / ELECTRICAL	blue electroluminescence electro-optic effect	LEDs, lasers, modulators, optical switches
ELECTRICAL	high resisitivity good dielectric constant	dielectrics, substrates
ELECTRICAL / MECHANICAL	good piezoelectric high SAW velocity	SAW devices, oscillators,sensors
MECHANICAL	hard	special abrasives
THERMAL	high conductivity pyroelectric	heat-sinks for ICs & high-power devices, IR detectors
CHEMICAL	refractory, stable to many molten metals (especially Al)	containers for III-V processing, aluminium industry

Potential Uses For Aluminium Nitride



Maximum rate of growth of AlN by sublimation (calculated)

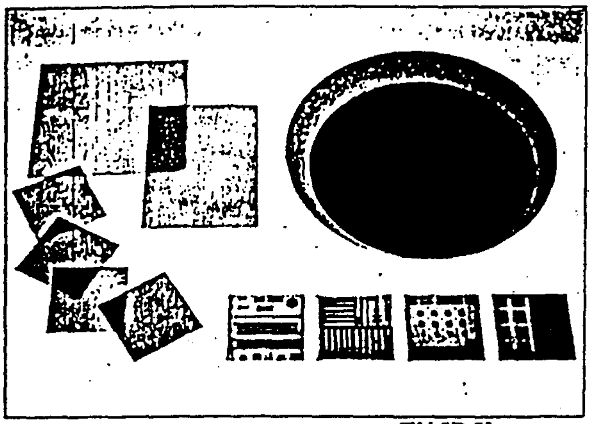

Energy gap (eV)
0
2
4
6
8
Lattice constant (Å)
3.0
4.0
5.0
6.0
BN
diamond
AlN
GaN
ZnO
SiC
α
β
CuAlS2
ZnS
ZnSiP2
ZnGeP2
CuGaS2
AlP
GaP
ZnSe
AgGaS2
AlAs
ZnSiAs2
CdS
GaAs
Si
ZnGeAs2
Ge
CuInSe2
InP
CdSe
AlSb

New product, TRANSLUCENT AℓN CERAMIC—*SHAPAL*™

SHAPAL™ is a unique, high thermal conductive ceramic to be applicable to various uses of high performance requirement.

Aluminum nitride (AℓN) is a unique material with excellent characteristics of high resistance to heat and corrosion, high thermal conductivity and good electric insulation. Single crystal, for example, has high thermal conductivity of 320 W/m·K as much as the theoretical value and has good transparency. Its sintered form, however, had not shown these characteristics until ultra high purity AℓN powder with good sinterability was produced by Tokuyama Soda.

Tokuyama Soda has developed the ultra high purity AℓN powder and produced its sintered articles with excellent properties comparable to its theoretically attainable values.



SHAPAL products

SHAPAL will show excellent performance when used for electrical and electronic applications, especially for substrates of various semiconductors.

Characteristics

(1) High thermal conductivity:	•About 10 times as much as that of alumina
(2) Excellent electrical properties:	•High resistivity and low dielectric constant and loss
(3) Mechanical strength:	•Higher than alumina
(4) High resistivity to corrosion:	•Inert to almost all molten metals
(5) Ultra high purity:	•Does not contaminate molten metals at high temperature

Translucency of *SHAPAL*

The see-through property is an advantage for visual inspection of the internal structure of ceramic.

(6) Translucency:	•Translucent to infra-red and visible light
(7) Reliability:	•Uniform structure guarantees consistent properties

Applications

(1) Circuit substrates of semiconductor module and IC package

(2) Heat sink materials of power transistor, thyristor, LD and LED

(3) Crucibles for molten metals and preparing single crystals

(4) Window materials for infra-red and radar

THERMAL EXPANSION COEFFICIENT OF ALUMINIUM NITRIDE

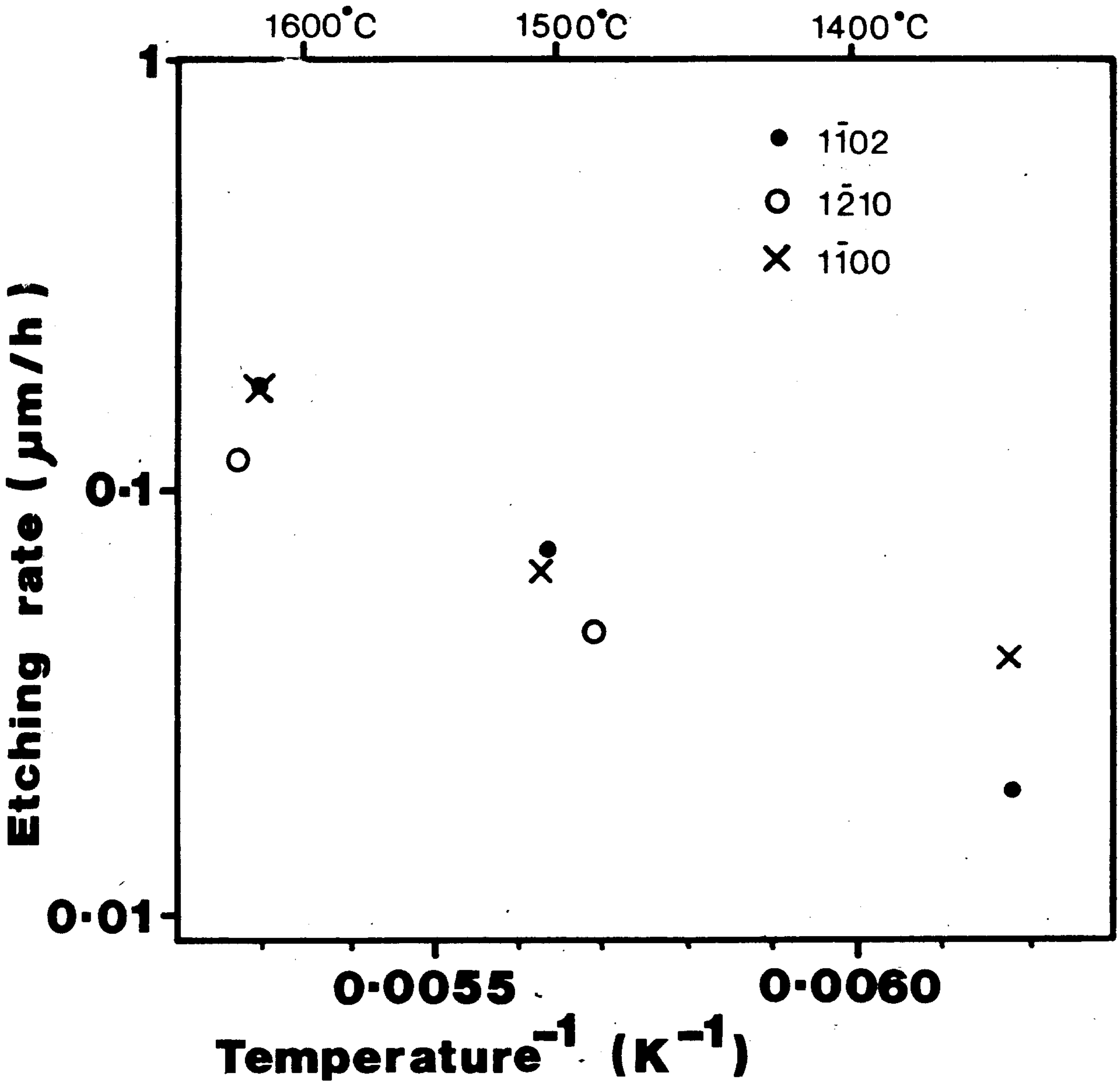
$$\alpha_{\perp c} = 5.3 \times 10^{-6} \quad \text{deg.}^{-1}$$

$$\alpha_{// c} = 4.2 \times 10^{-6}$$

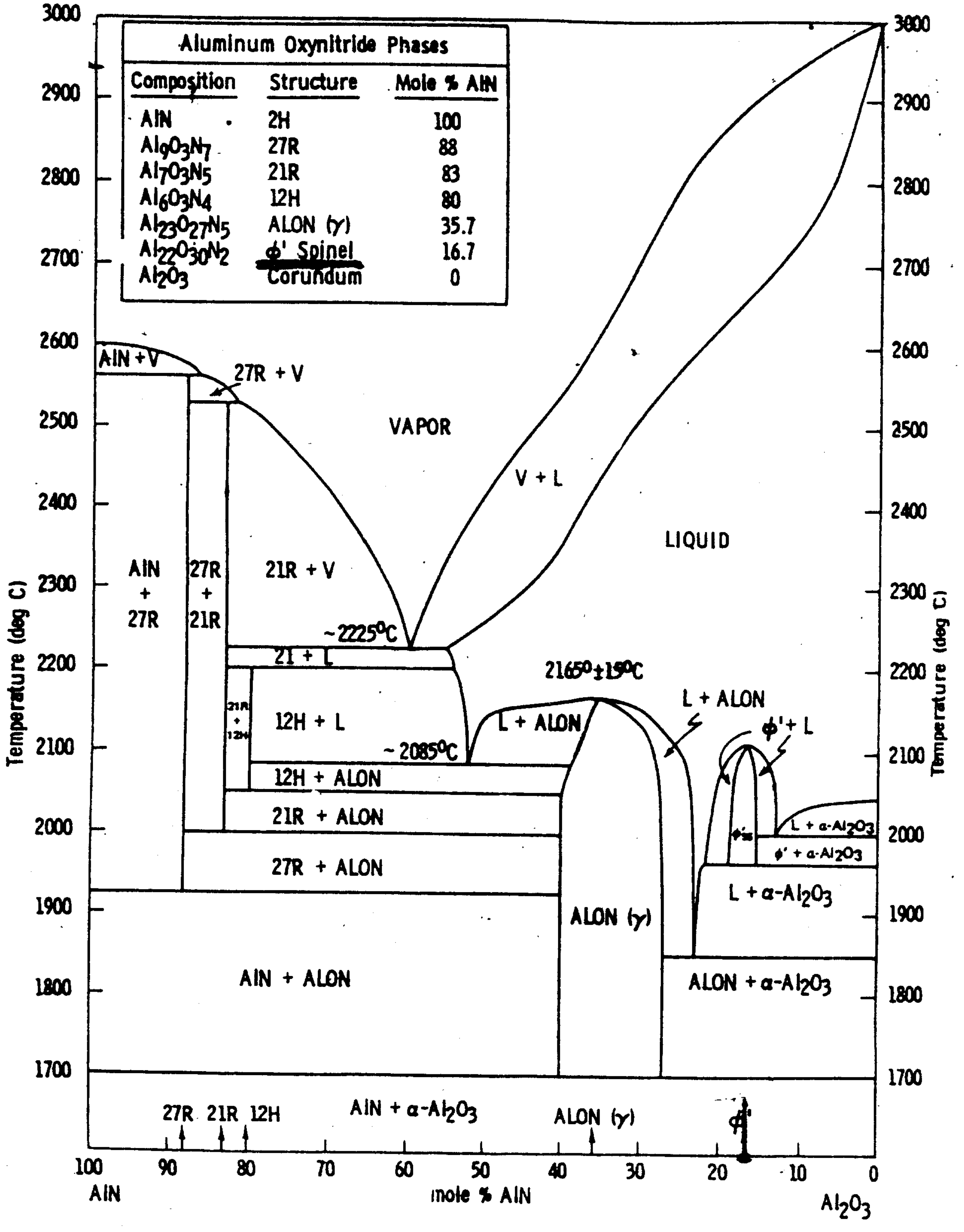
Compare α of sapphire:

$$\alpha_{\perp c} = 7.7 \times 10^{-6}$$

$$\alpha_{// c} = 8.1 \times 10^{-6}$$



Reaction of sapphire with nitrogen
(temperature dependence of etching rate)



Phase diagram for the system Al_2O_3 - AlN
(after J.W.McCauley & N.D. Corbin)

SUBLIMATION OF AlN

$$AlN_s \rightarrow \left(Al_g + \tfrac{1}{2} N_{2\,g}\right) \rightarrow AlN_s$$

STEPS:

1. $AlN_s \rightarrow Al_{ads} + N_{ads}$

2. $Al_{ads} \rightarrow Al_g$

3. $N_{ads} \rightarrow \tfrac{1}{2} N_{2\,ads} \rightarrow \tfrac{1}{2} N_{2g}$

[redacted]

Facetted crystals of aluminium nitride