The All India Glass Manufacturers' Federation

in partnership with:

Workshop on Future of Security Glasses

(March 27, 2026)

at K.R. Mangalam University, Sohna Road, Gurugram, Haryana 122103

TRANSPARENT GLASS-CERAMICS FOR ARMOR

Dr. Atiar Rahaman Molla

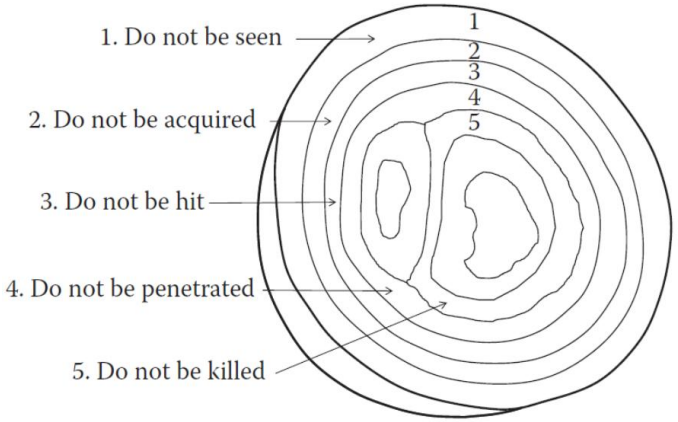
Scientist – F

Specialty Glass Division

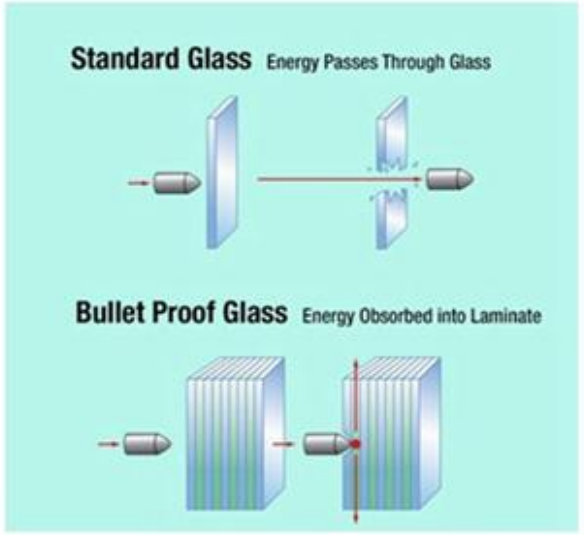
CSIR-Central Glass and Ceramic Research Institute, Kolkata

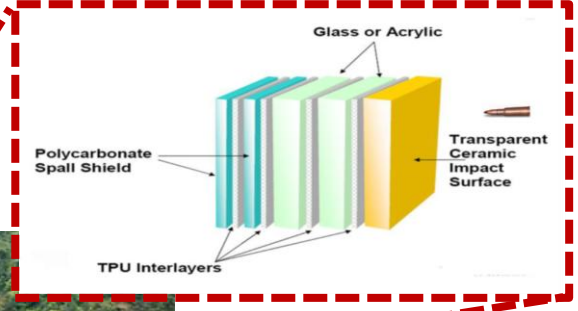
atiar.cgcri@csir.res.in

The Concept of Armour



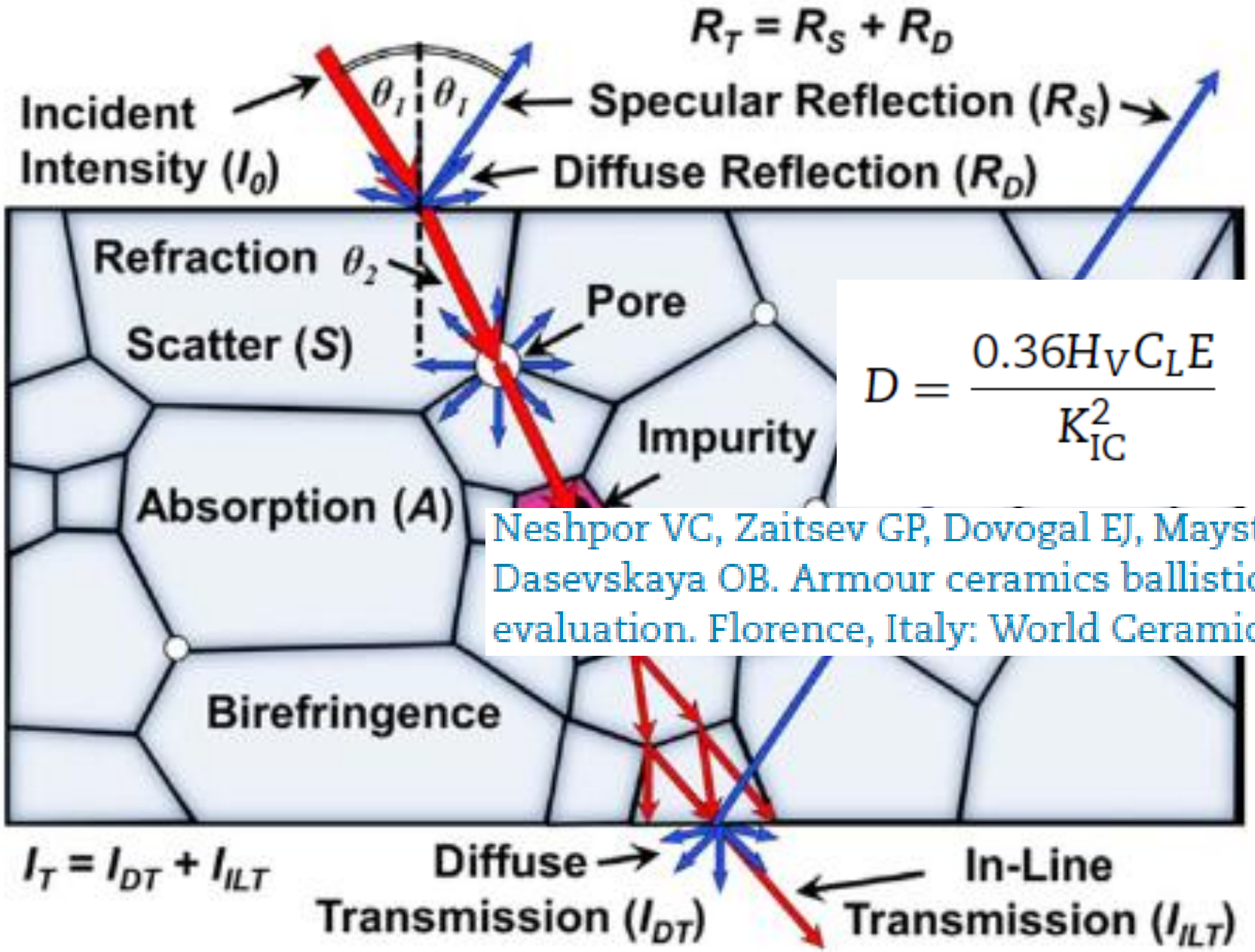
Onion approach to survivability





Conventional Glass Armor	Proposed GCs Armor
SLS glass based multi-layered, heavy, low cost, more layers	Stronger glass-ceramics based multilayered, lightweight, less layers
Properties of SLS glass Density: 2.5 g/cc Young's modulus: 68-72 GPa Vickers Hardness: 4.4-4.8 GPa Fracture Toughness: 0.55-0.7 $MPam^{1/2}$ Flexural Strength: 30-35 MPa CTE: 9.1-9.5x$10^{-6}/^0C$	**Properties of MAS GCs** Density: 2.59 g/cc Young's modulus: 80-90 GPa Vickers Hardness: 9.5-10 GPa Fracture Toughness: >2 $MPam^{1/2}$ Flexural Strength: 200-350 MPa CTE: 3.3-3.4x$10^{-6}/^0C$
Applications: HMMWV, bullet-proof cars, helicopters, combat aircrafts etc.	

- Glass based armor is heavy and has a high areal density 160-180 kg/m^2
- Transparent ceramic-based armors are excellent but exorbitantly costly,
- No technologies or equipment are available in India to produce such materials in the required dimensions and shapes.
- **The GCs-based Armors exhibit superior strength and high transparency, along with the flexibility to produce in large sizes and complicated shapes at a reasonable cost.**
- **The areal density is aimed to reduce to <120 kg/m^2**



$$D = \frac{0.36 H_V C_L E}{K_{IC}^2}$$

Neshpor VC, Zaitsev GP, Dovogal EJ, Maystrenko AL, Dasevskaya OB. Armour ceramics ballistic efficiency evaluation. Florence, Italy: World Ceramics Congress; 1995.

Cost

Glass is an ideal
armor applicatio
hardness and du
and brittle

parent
y, high
weak

Can glass b TEEL?

Theoretical stren is **35 GPa**
in a tensile mode
Ordinary soda-lir in a brittle
mode at as little

The tensile stre l is 0.4 GPa

(~1 % of theoretical strength of a flawless glass)

...e energy

...urther

Shards are kep...

canyon skywalk)

✓Thermal tempering: Adds ... f...

windshields)

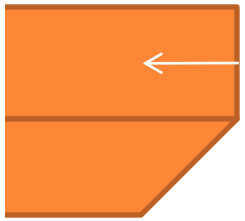
✓Over glazing with lower t...

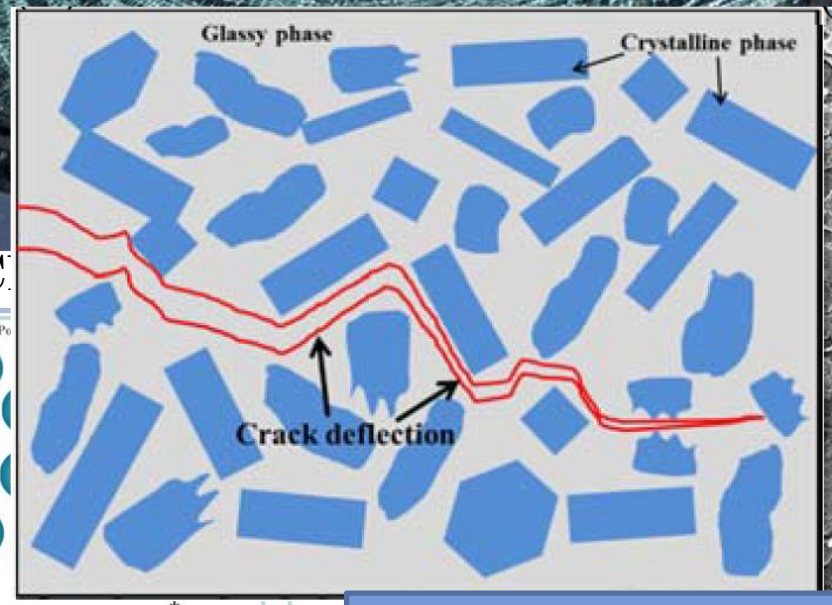
✓Inclusion of a second phas...

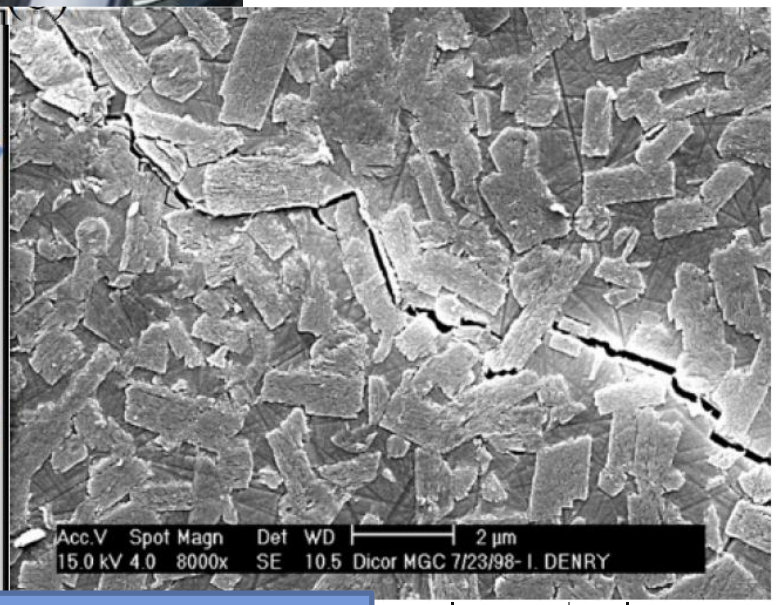
✓Ion Exchange (Chemical) streng...

compression.

sive Stress







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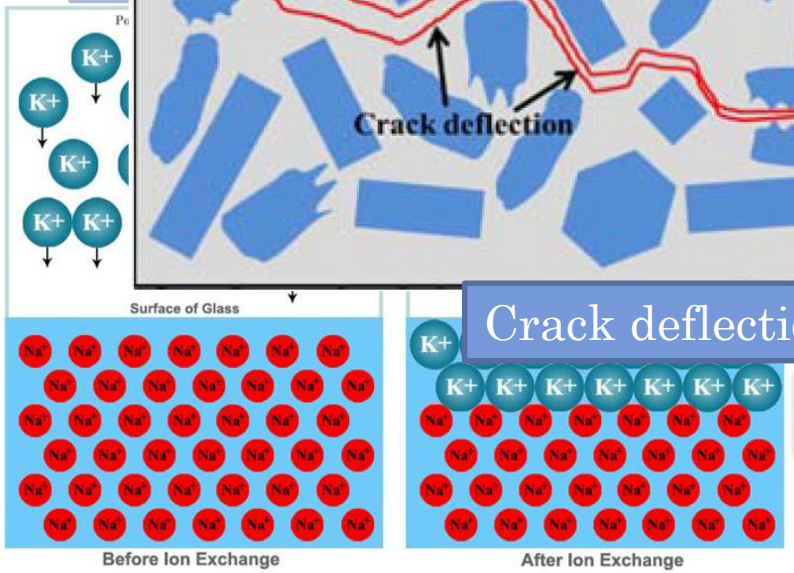
pression tension

Crack deflection mechanism in GCs

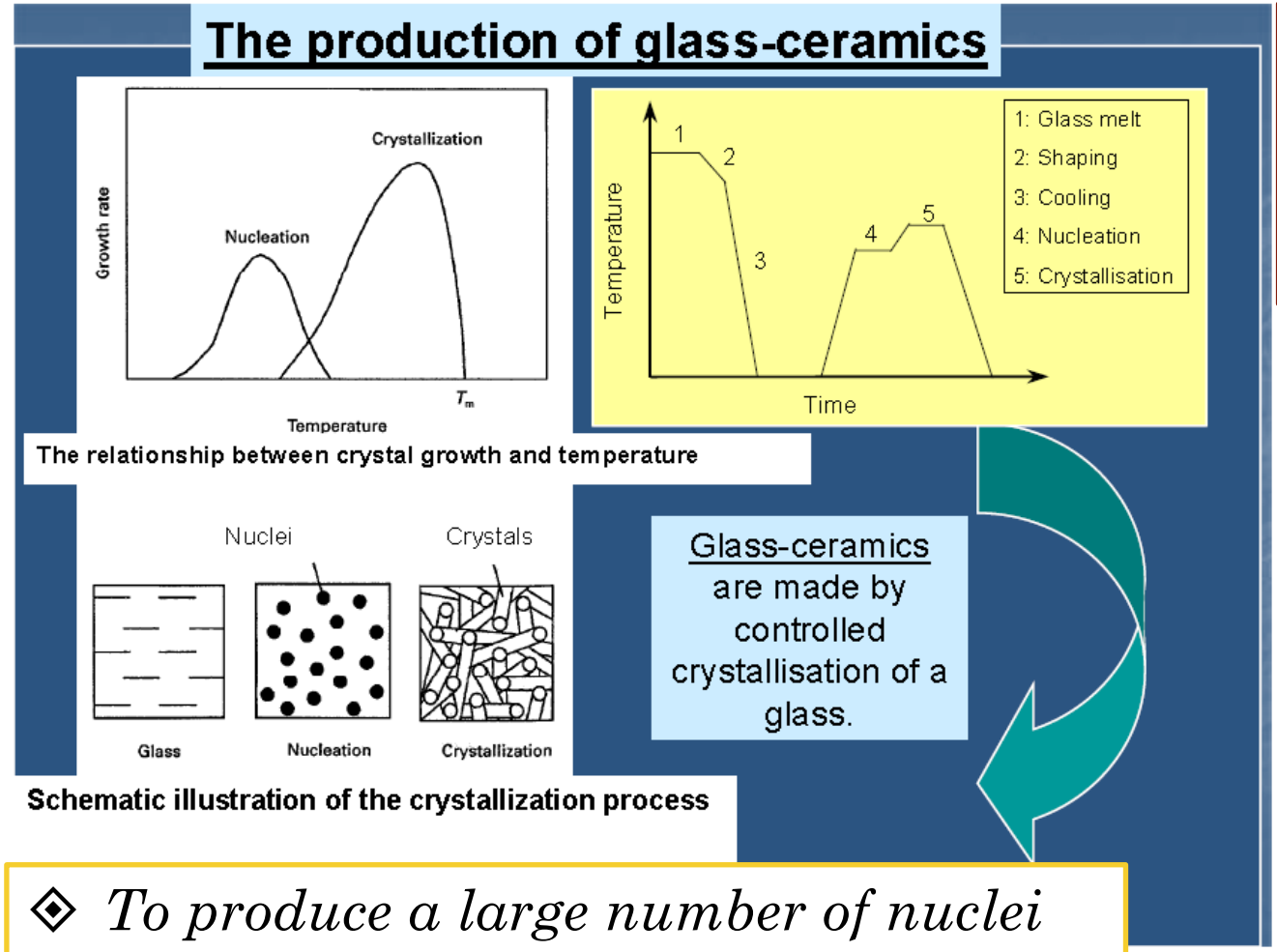


-70 to -150 MPa Surface compression

- 0.5 GPa

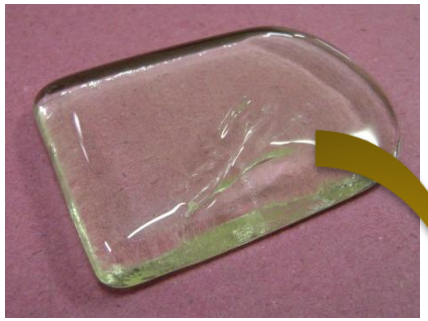
GLASS-CERAMICS

Glass-ceramics are polycrystalline solids prepared by the controlled crystallization of glasses



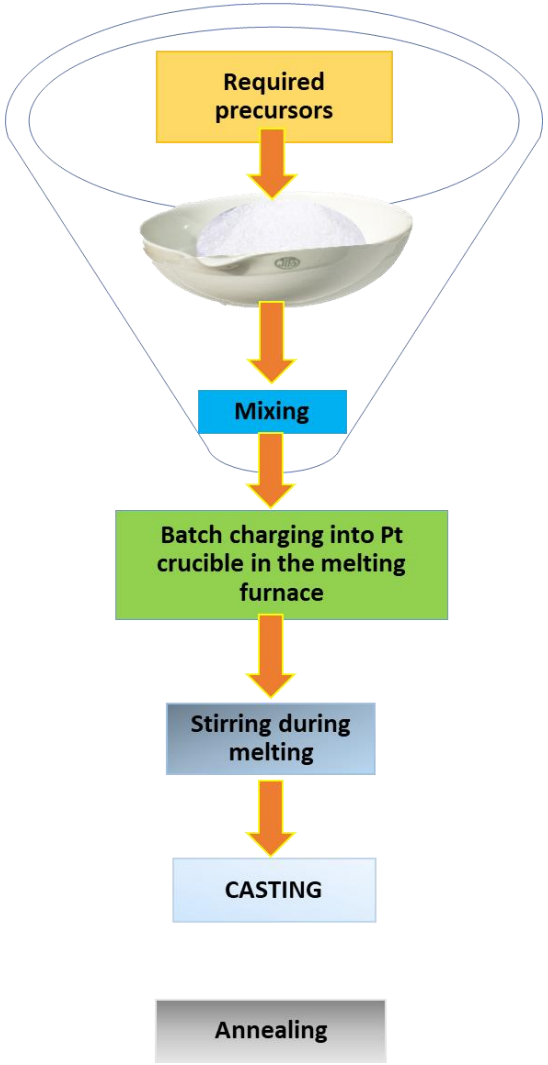
Glass-ceramics: Controlling factors of Properties:

- ✓ **Composition**
- ✓ **Ceramization**

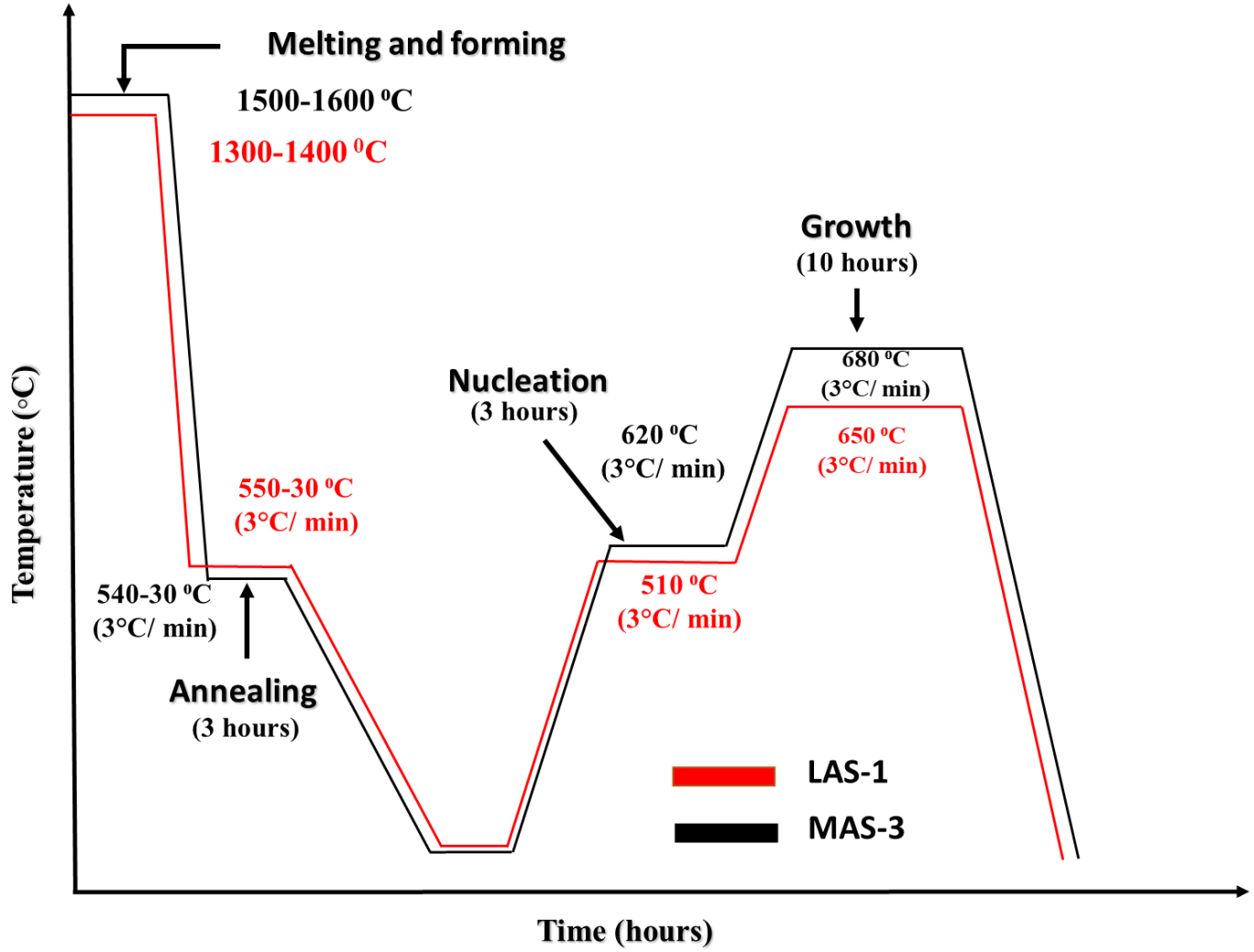


- ◈ *To produce a large number of nuclei*
- ◈ *Controlled crystallization of glasses*

Optimized development route of LAS and MAS-based glass along with their individual ceramization process



Development Route



Optimization of Ceramization Process

GLOBAL SCENARIO OF NEXT-GENERATION MATERIALS DEVELOPMENT FOR ARMOR SYSTEM

Internationally, researchers are working on transparent ceramics/GCs such as

- ALON, spinel, and sapphire based transparent ceramics
- Commercially available glass-ceramics : lithium-alumo-silicate glass ceramics (SCHOTT's ROBAX®), or a lithium-disilicate glass ceramic such as ALSTOM's TRANSARM®
- Magnesium alumina silicate (MAS) based glass-ceramics are not yet commercially available

INDIAN SCENARIO

- Transparent GC armors are not yet developed or produced in India

GLOBAL MARKET AND FUTURE PROJECTIONS

Due to incremental threats, the ballistic protection market is projected to grow from USD 13.4 billion to 16.9 billion by 2027, at a CAGR of 4.7 % from 2022 to 2027.

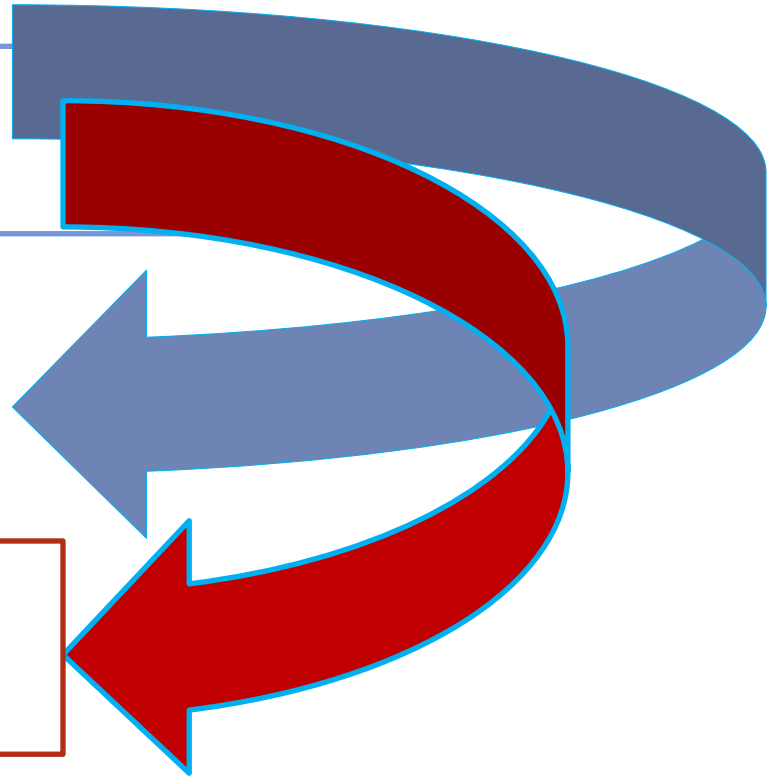
Challenges to develop GCs for armors

Transparency ∝ 1/
Mechanical strength

1. To achieve transparency ~85-90 %
2. High mechanical properties in GCs

Crystal Size
Matching refractive index between glass and crystal phase

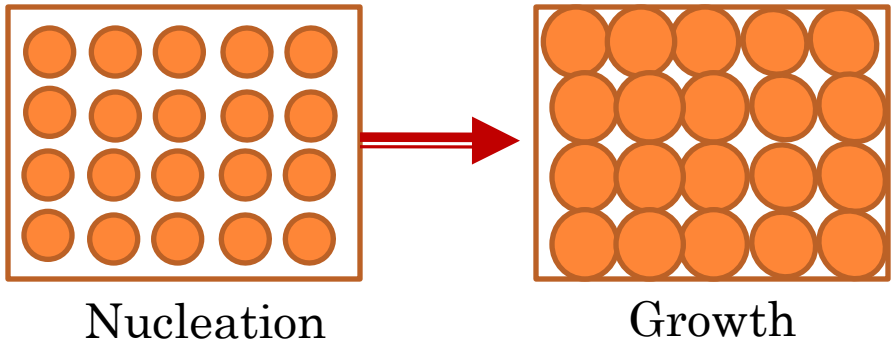
Homogeneous distribution of nano-crystals
Desired crystal phase
Surface strengthening

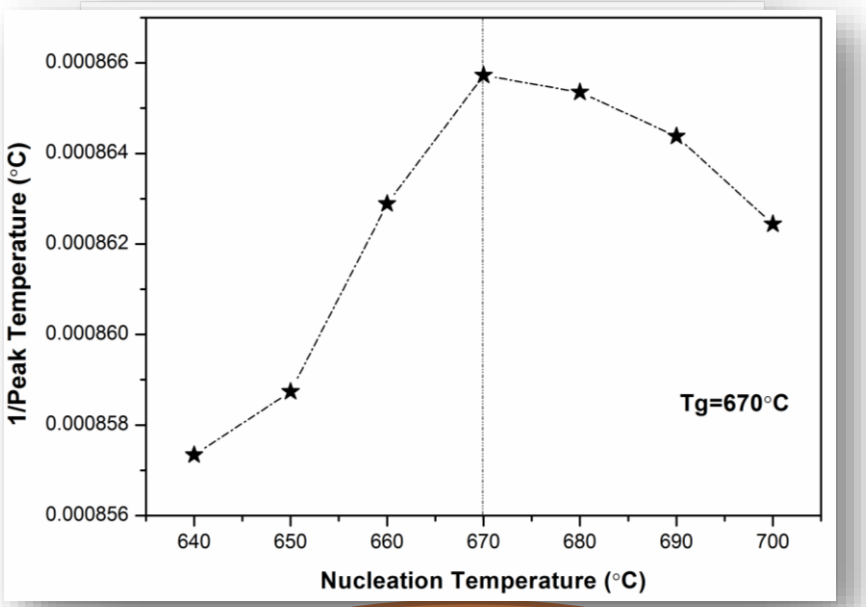


How to overcome challenges

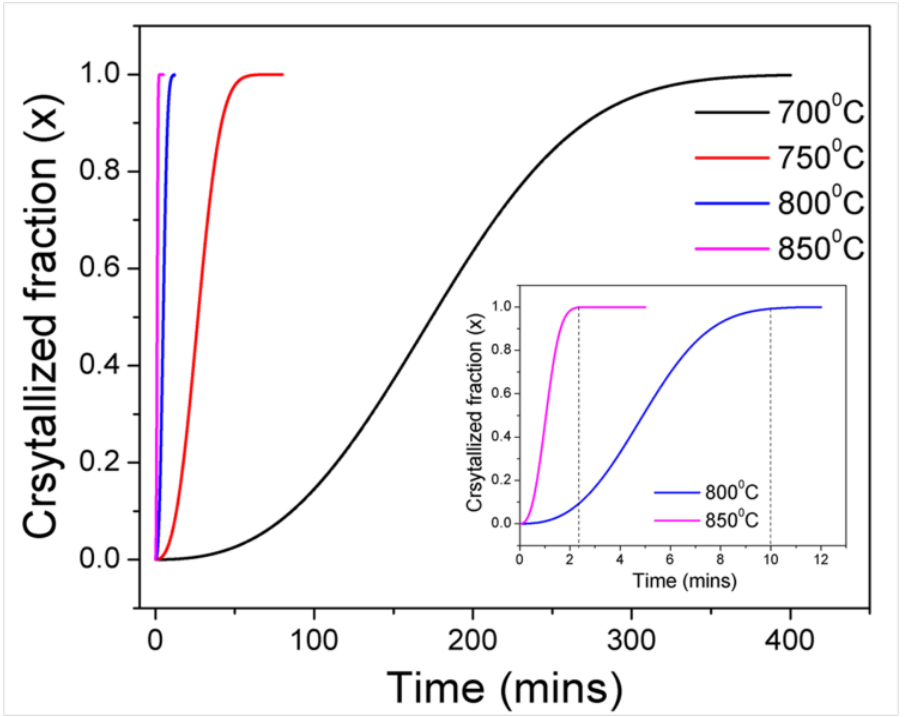
Composition optimization
Controlled Crystallization

The glass to be heat treated at the nucleation temperature (T_N) where nucleation rate is the highest





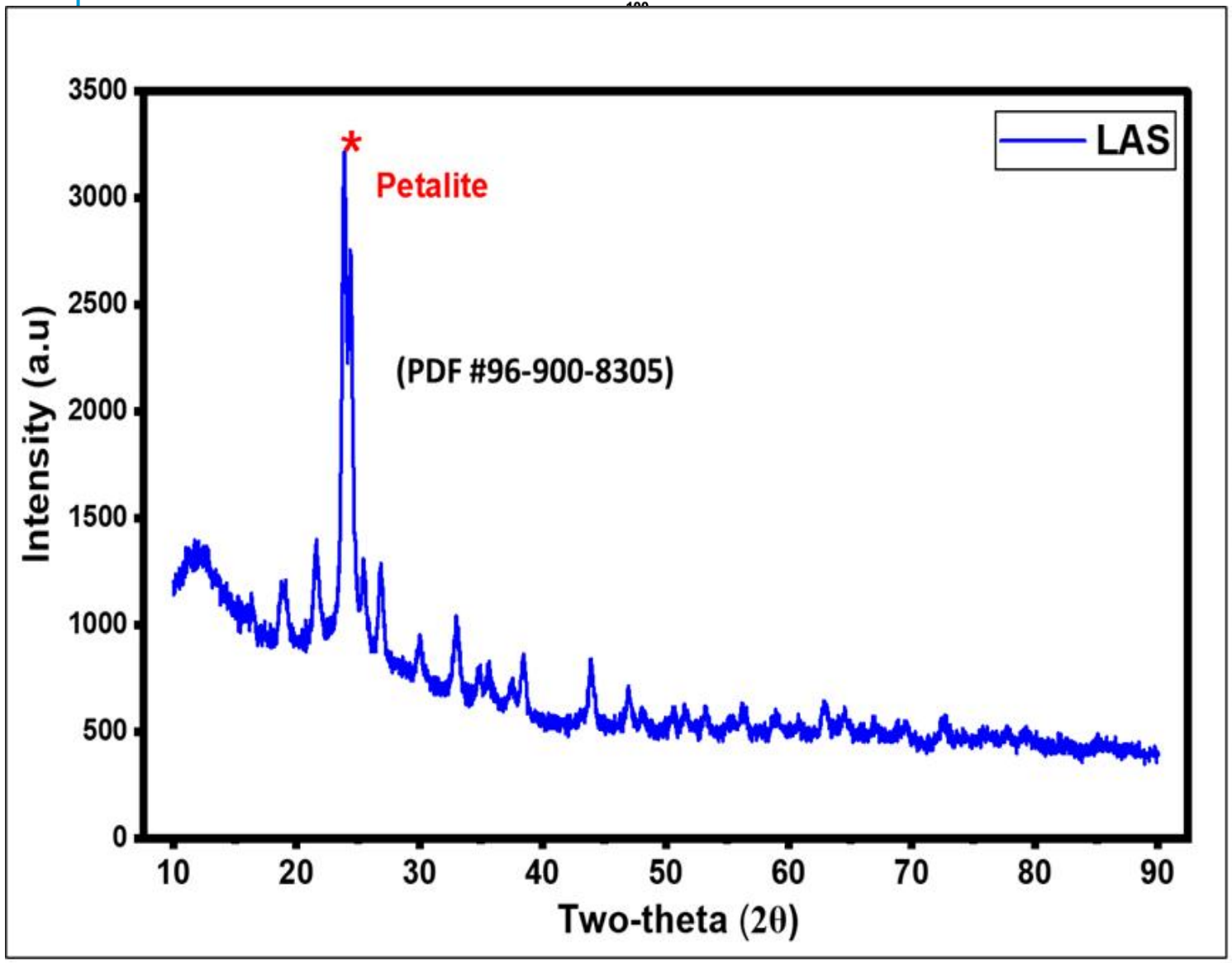
Avrami Index

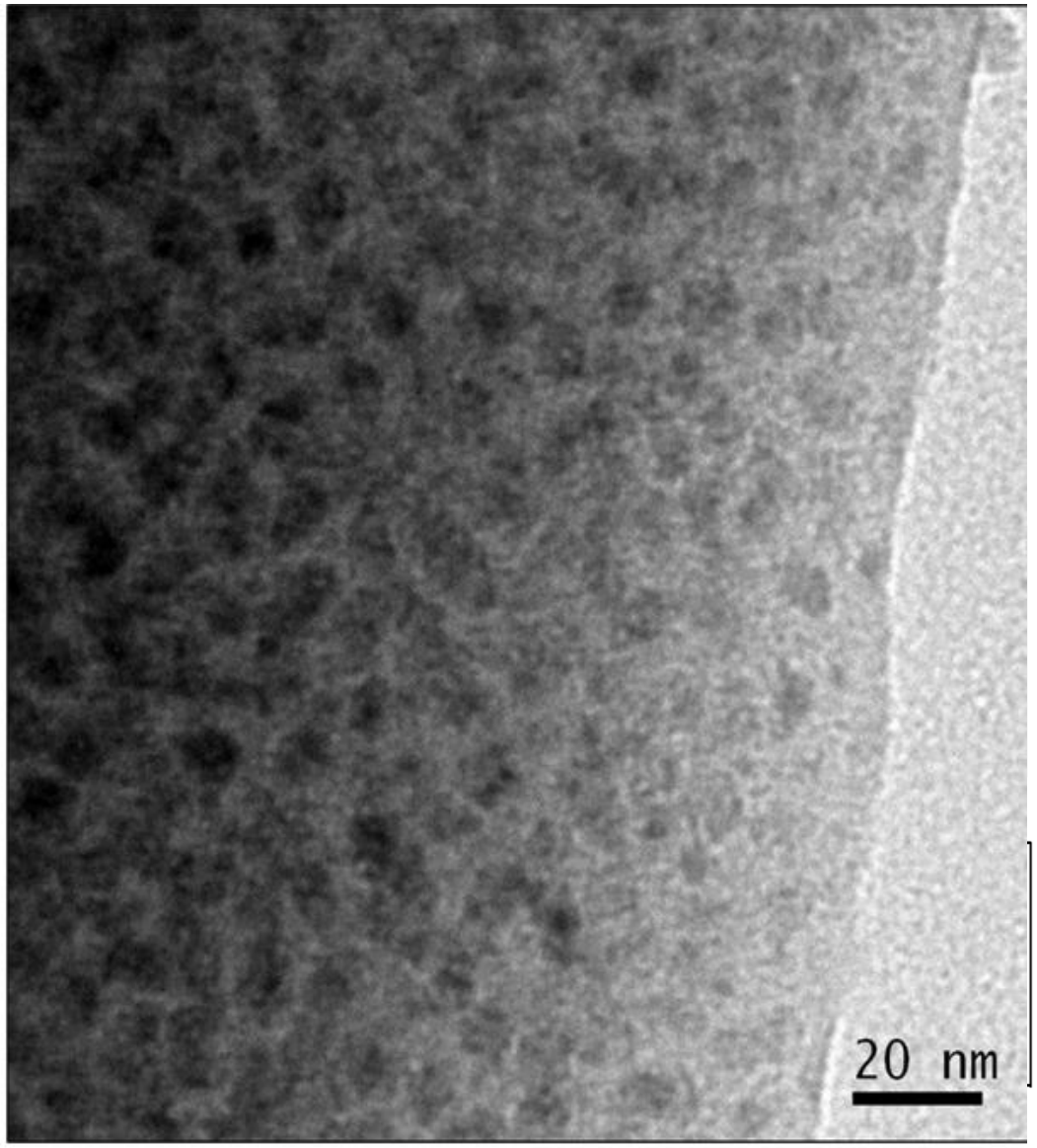


Determination of optimum heat-treatment protocol through crystallization kinetics

SUMMARY OF KEY RESULTS / ACHIEVEMENTS

Development of LAS GC

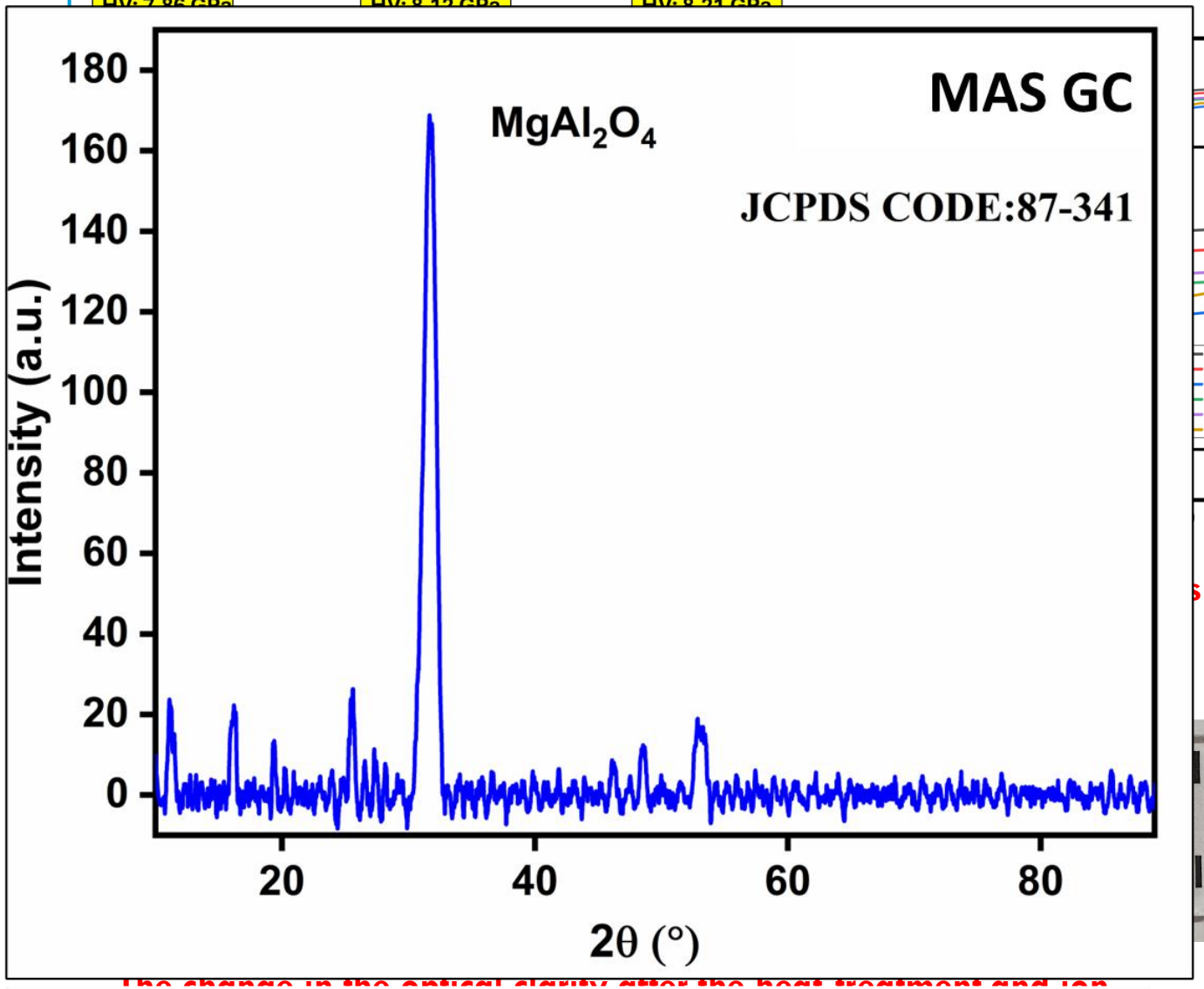


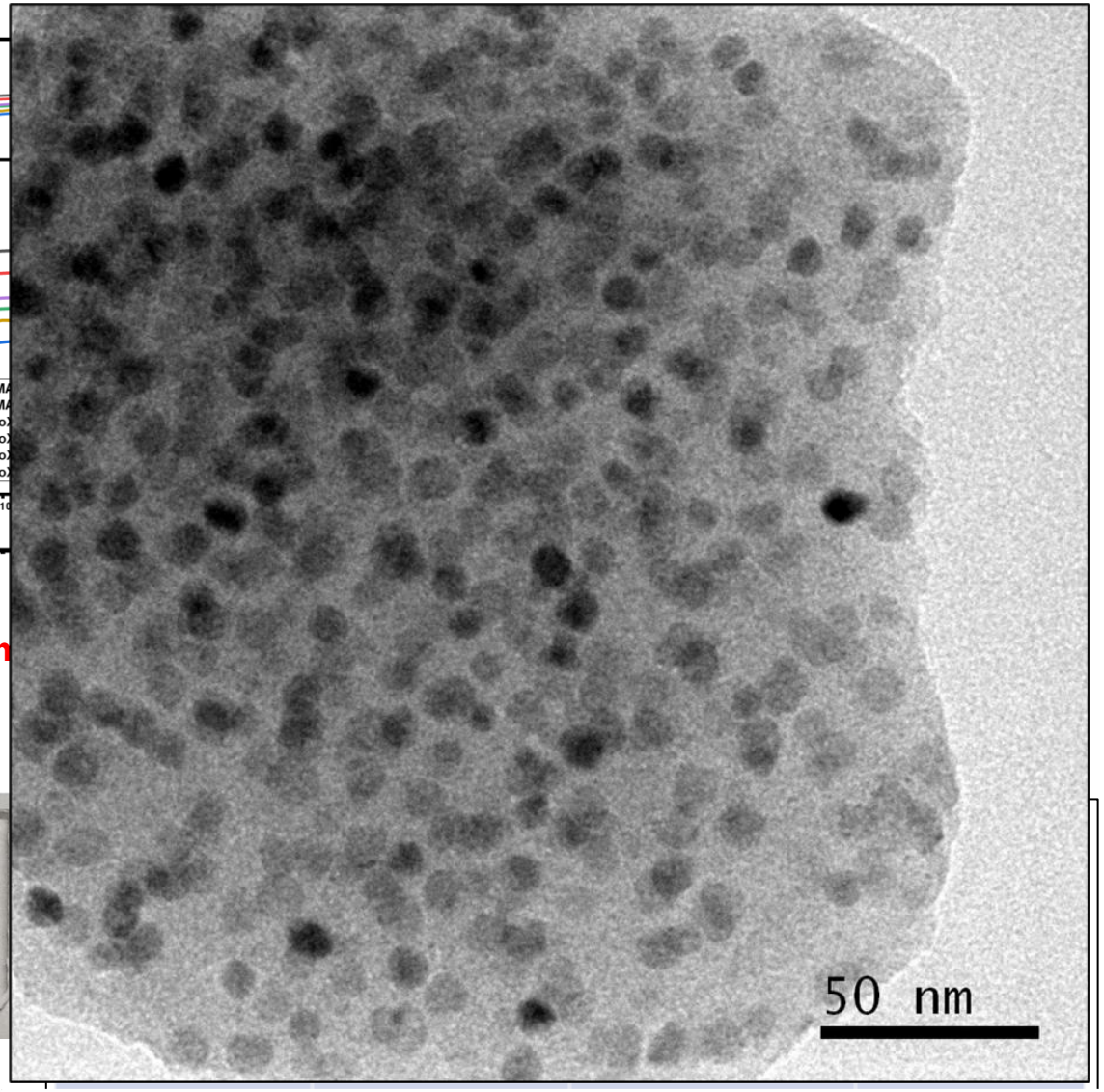


- XRD confirmed the petalite crystal phase with the PDF #96-900-8305
- TEM analysis confirmed the crystal size below 20 nm

SUMMARY OF KEY RESULTS / ACHIEVEMENTS

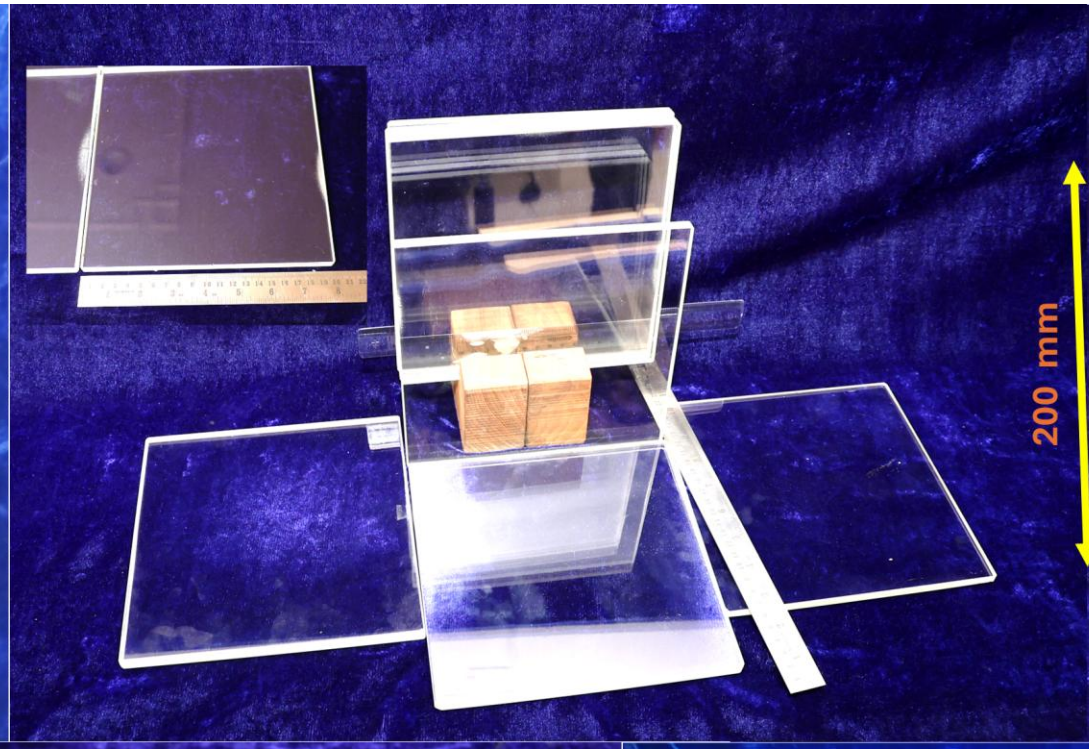
Development of MAS GC

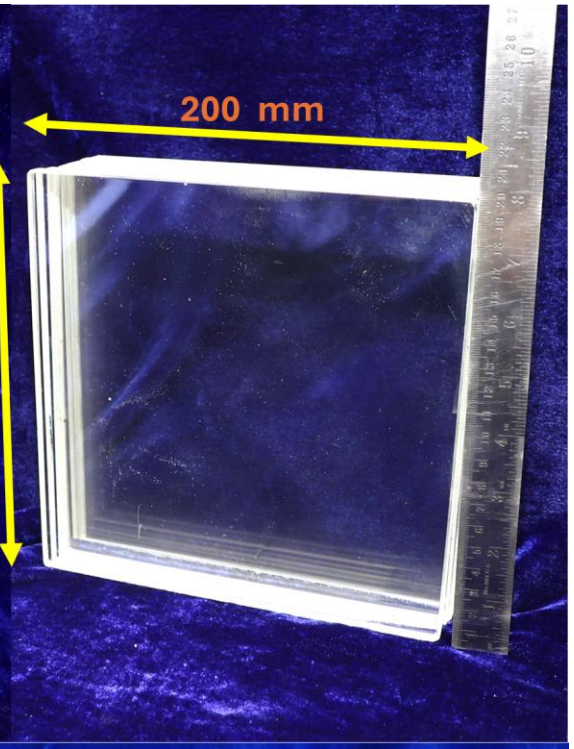


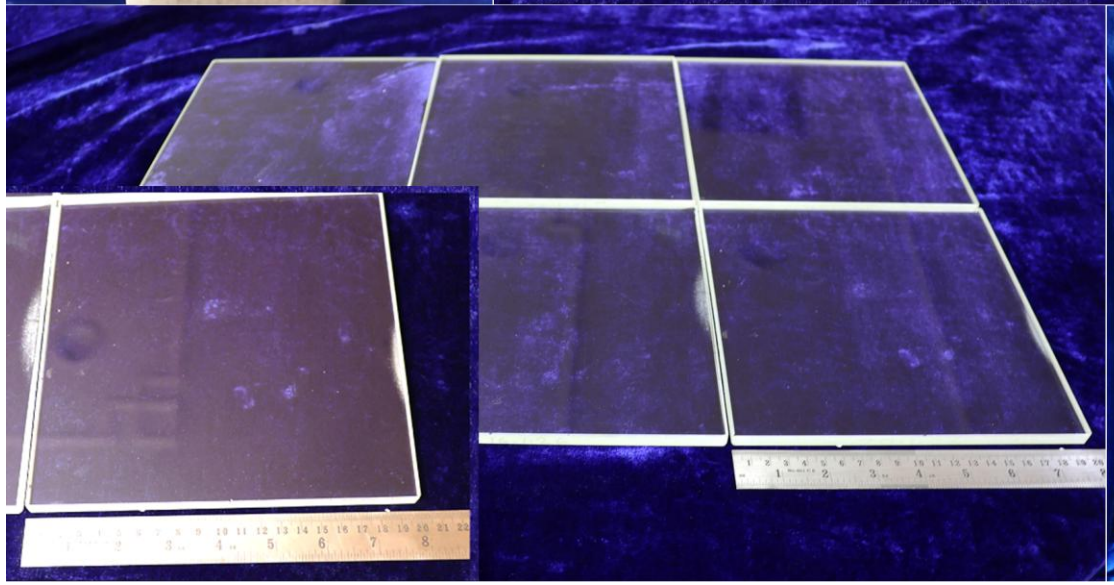


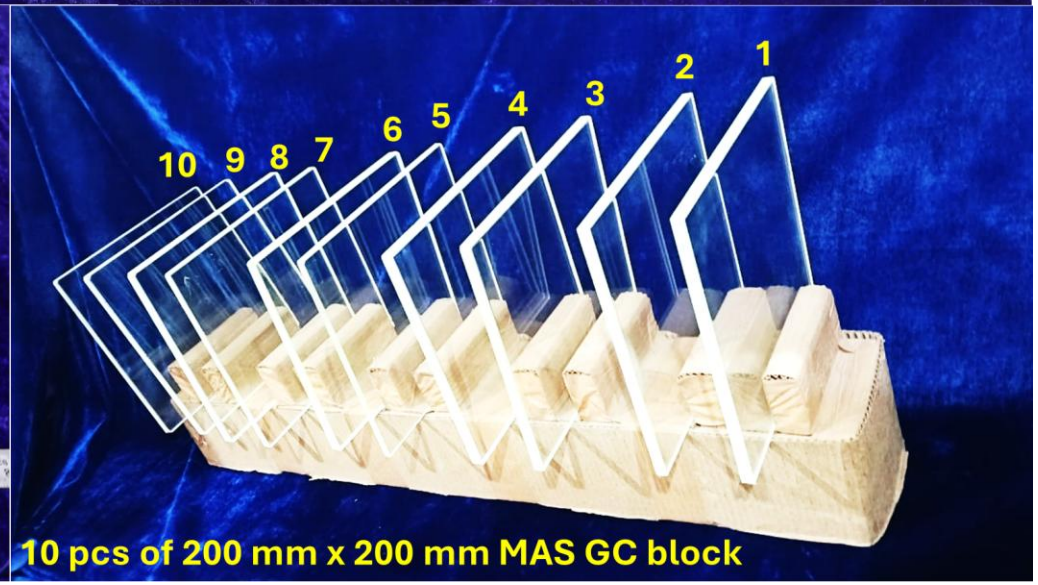
- XRD confirmed the Magnesium Aluminate Spinel ($MgAl_2O_4$) phase
- TEM analysis confirmed the crystal size within the range of 10-15 nm

MAS GC samples of size up to 200 mm x 200 mm fabricated at CGCRI

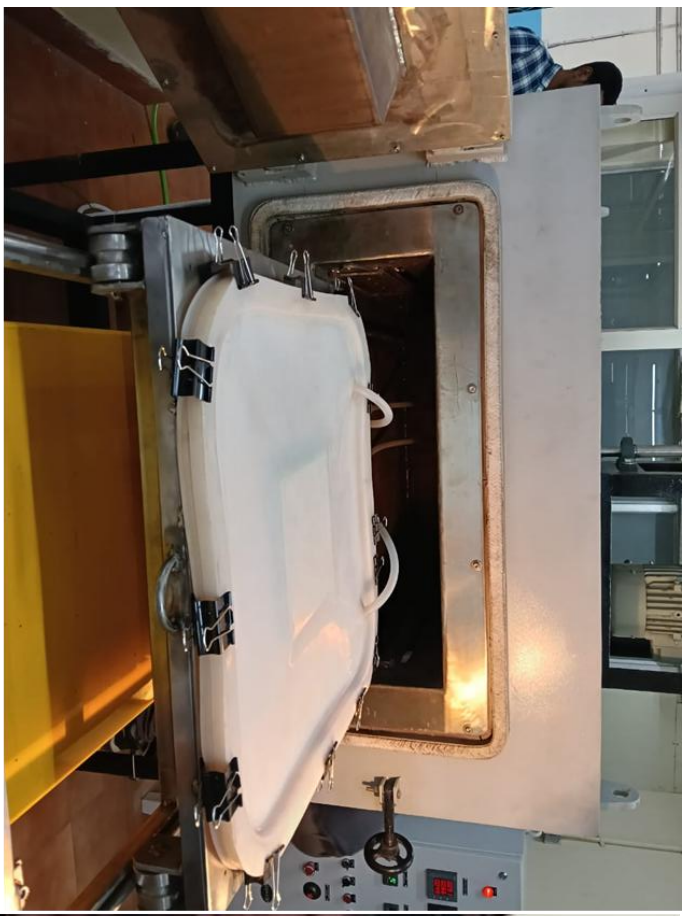








Lamination machine installed in CSIR-CGCRI



BENCHMARKING OF DEVELOPED TECHNOLOGY/PROCESS/PRODUCT

Properties	ALON Ceramics	SLS Glass	SCHOTT's ROBAX®	ALSTOM's TRANSARM®	CGCRI-MAS GC	CGCRI-LAS GC IoX
Visible Transparency (%) for 2 mm (t)	80	~80-90	80-90	80-90	88	80.66
Density (g/cc)	3.7	2.45-2.52	2.6	2.5-2.8	2.6	2.432
CTE (10^{-6}/K)	4.7	9.0-9.5	0±0.5	0-5	7.26	8.19
Strength (3-point Bending) MPa	380–700	120-125	35	119-172	405	408
Vickers' hardness (GPa)	13-18	4.5-4.7	4.41	6-7	8.9	8.91
Elastic Modulus (GPa)	334	72-73	92-93	95-115	96.5	97.2
Fracture Toughness (MPa·$m^{0.5}$)	2.0	0.75-0.78	0.82 ± 0.03	1.0-2.4	3.56	3.63
Compressive Strength (GPa)	2.68	1.500-1.700	0.02-0.2	1.0-1.2	0.614	0.74
EM transparency at 2-10 GHz, (a) Dielectric constant (b) Loss Tangent		5-10 0.003-0.007			5.8-8.4 0.006-0.007	Not yet done
Areal Density (kg/m^2) For NIJ threat level III	80–120	160-180	90-100	Not reported	Not yet done	Not yet done

Controller General of Patents,
Designs & Trade Marks

सत्यमेव जयते

G.A.R.6
[See Rule 22(1)]
RECEIPT

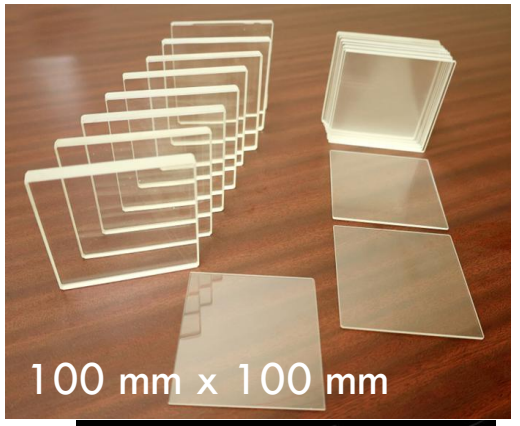
INTELLECTUAL PROPERTY INDIA
PATENTS | DESIGNS | TRADE MARKS
GEOGRAPHICAL INDICATIONS

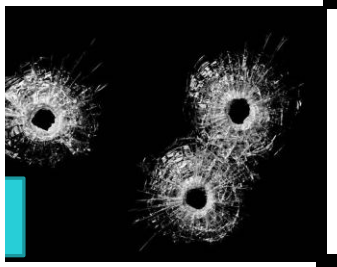
Docket No 15608

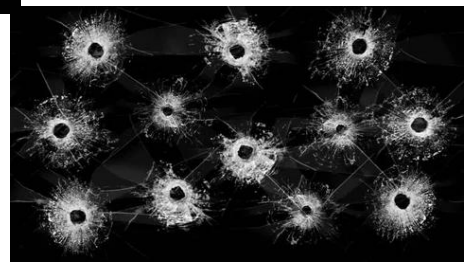
Date/Time 2026/02/04 10:39:00

Dr Seema Innovation Protection Unit (IPU), CSIR NISCAIR Building 3rd Floor 14 Satsang Vihar Marg Email: seema.ipu@csir.res.in

Sr. No.	App. Number	Ref. No./Application No.	Amount Paid	C.B.R. No.	Form Name	Fee Payment	Remarks
1	202611012291	TEMP/E-1/10995/2026-DEL	8000	7068	FORM 1	Full	A PROCESS FOR SYNTHESIS OF HIGH-STRENGTH, TRANSPARENT MAGNESIUM ALUMINATE SPINEL (MGAL2O4) GLASS-CERAMICS FOR ARMOUR APPLICATIONS







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B-28 Bhukhanvala Chambers, 8th Floor,
Off Link Veera Desai Road, Andheri West,
Mumbai 400053, Maharashtra, India.
T: +91-22-40649000 | F: +91-22-66920604
E: info@bhukhanvala.in | W: www.bhukhanvala.in
CIN : U29100MH1987PTC042304

To,
The Director
CSIR-Central Glass and Ceramic Research Institute
196, Raja S. C. Mullick Road
Kolkata – 700032
Ph: +91-33-23223340, Fax: +91-33-24730957
E-mail: director.cgcri@csir.res.in
Date `18.08.2025

Kind Attention: Dr. Atiar Rahaman Molla, Senior Principal Scientist

Subject: Collaboration with CSIR-CGCRI on the research project "Development of lightweight, ultra-strong transparent glass-ceramics for armoured vehicles and combat aircraft to reduce the areal density"

Dear Prof. Basu,

This has reference to our recent meeting and subsequent discussion with your colleague, Dr. Molla, during the Industry Conclave organized by CSIR-CGCRI at Kolkata. I was pleased to learn that your esteemed Institute is engaged in a significant research project titled "Development of lightweight, ultra-strong transparent glass-ceramics for armoured vehicles and combat aircraft to reduce the areal density" with financial support from DRDO and CSIR, Government of India.

As you are aware, there is an urgent demand for advanced transparent armor materials with superior strength and reduced areal density for application in armored vehicles, helicopters, and related defence platforms.
The concept of developing glass-ceramic based transparent armor, as envisioned by your team, is indeed innovative and has the potential to substantially outperform currently available glass-based armors.

Our company, being actively engaged in Advanced material technologies for defence applications, would be delighted to collaborate with CSIR-CGCRI in this endeavor. In particular, we would be glad to extend our testing facilities for evaluating your developed samples. Furthermore, we express keen interest in exploring opportunities for commercial production of this technology once the project objectives are successfully achieved, thereby contributing to the nation's strategic requirements.
We look forward to a fruitful collaboration with your Institute.

Thanking you,

Yours faithfully,
For Bhukhanvala Industries Private Limited

Niraj P. Bhukhanwala
Managing Director

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mic Research Institute,
Kolkata - 700032.

boration on the Research Project – "High Strength Transparent d Vehicles"

our ongoing research project on "High Strength Transparent Glass-hicles", supported by DRDO/CSIR, Government of India. The , transparent glass-ceramics holds immense potential for advanced e display applications. Your innovative approach to developing rent armor with superior strength is indeed commendable and has e performance of conventional glass-based displays and armor

acturers of induction melting furnaces in the country, our company uch furnaces to several prominent organizations, including ISRO, vernment and private sectors. Given our extensive experience in ies and your promising research, we believe that this technology has tential. We would be highly interested in collaborating with your ibilities of scaling up this technology for commercial production to emand for high-strength transparent armor materials.

to a fruitful collaboration with your institute to facilitate the s technology for national benefit. Please feel free to reach out for any itiate this collaboration.

ita- President –Operation –Induction heating and Hardening for you for any further technical discussion, meetings with you, your team, fficers for this project.

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ur time and consideration.

td.

edabad), Gujarat-382115, India.
: +91-2717-234866

REGD. OFFICE:
A-1, Skylark Apartment, Satellite Road,
Satellite, Ahmedabad-380015.
Phone: +91-79-26768844, Fax: +91-79-26768855

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BOROSIL RENEWABLES LIMITED
CIN : L26100MH1962PLC012538
Regd. Office: 1101, Crescenzo, G-Block, Opp. MCA Club, Bandra Kurla Complex
Bandra (E), Mumbai – 400 051, India.
T : +9122 6740 6300
F : +9122 6740 6514
W : www.borosilrenewables.com Email : brl@borosil.com

Date: September 15, 2023

Dr. Atiar Rahaman Molla
SENIOR PRINCIPAL SCIENTIST,
CSIR-Central Glass and Ceramic Research Institute,
196, Raja S. C. Mullick Road, Kolkata - 700032.
Ph:+913323223340, Fax:+913324730957
E-mail: atiar@cgcri.res.in

Subject: **Regarding Collaboration with your Institute on the research project on "Development of lightweight, ultra-strong transparent glass-ceramic material and fabrication of laminated armor panels thereof for armored vehicles, combat aircraft to reduce the areal density"**

Dear Dr. Molla,

I am happy to learn that you're planning for a research project on "**Development of lightweight, ultra-strong transparent glass-ceramic material and fabrication of laminated armor panels thereof for armored vehicles, combat aircraft to reduce the areal density**" and seeking financial supports from CSIR, Government of India.

There is a huge demand for a much stronger transparent material for armor applications specially to reduce the areal density of armored vehicles, combat air crafts, etc. Your idea for glass-ceramics based transparent, stronger glass-ceramics armor is indeed a novel one and can outperform the existing glass-based armors.

Our company is working in the area of glasses and will be happy to collaborate with you in these endeavors, especially when you need industrial scale trial melting in order to upscale the technology, our factory facilities can be extended to you on a mutually agreeable basis. Moreover, we will be much interested to take this technology for commercial production on a mutually agreeable basis once it is viably developed and project objectives are met for catering to the needs of our country.

Looking forward for a useful collaboration with your Institute.

Thanking you and with kind regards,

Yours sincerely,
Dr. Jeetendra Sehgal
President – Business R&D
Borosil Renewables Limited, Pune

Borosil Renewables Limited PUNE

rks:
deshwar-Rajpipla Road,
age Govasi, Tal. Jhagadia,
t. Bharuch- 393001,
ujarat), India
+91 2645-258100
+91 2645-258235
brl@borosil.com

प्रशांत तु. रोजतकर
उत्कृष्ट वैज्ञानिक
निदेशक

Prashant T. Rojatkar
Outstanding Scientist
Director

कार्यालय / Off. : 0251 -2623037
फैक्स / Fax : 0251 -2623004
ई - मेल / E - mail. : director@nmrl.drdo.in
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पिन - 421 506
Govt. of India, Ministry of Defence
Defence Research & Development Organisation
NAVAL MATERIALS RESEARCH LABORATORY
Shil Badlapur Road, Addl. Ambernath (E), Maharasht
Pin - 421 506

DO.NO. : NMRL/MISC/TA/2022/03 Mar 2023

Dear Dr Suman Kumari,

Appreciation towards development of spinel based glass-ceramics by CGCRI

A ballistic test panel was developed by NMRL using spinel based glass-ceramic positive and encouraging. I am glad to inform you that the test panel could successfully stop the ammunition fired from a distance of 10m at a reference velocity of 695±20 m/s. A copy of the trial report is being forwarded for your perusal.

I would like to convey our sincere appreciations to CGCRI for successful development of spinel based glass-ceramics which can potentially be used for transparent armour applications. We are also looking forward to a collaborative research work between NMRL and CGCRI for development of lighter and optically transparent bullet-resistant wind shields for defence vehicles.

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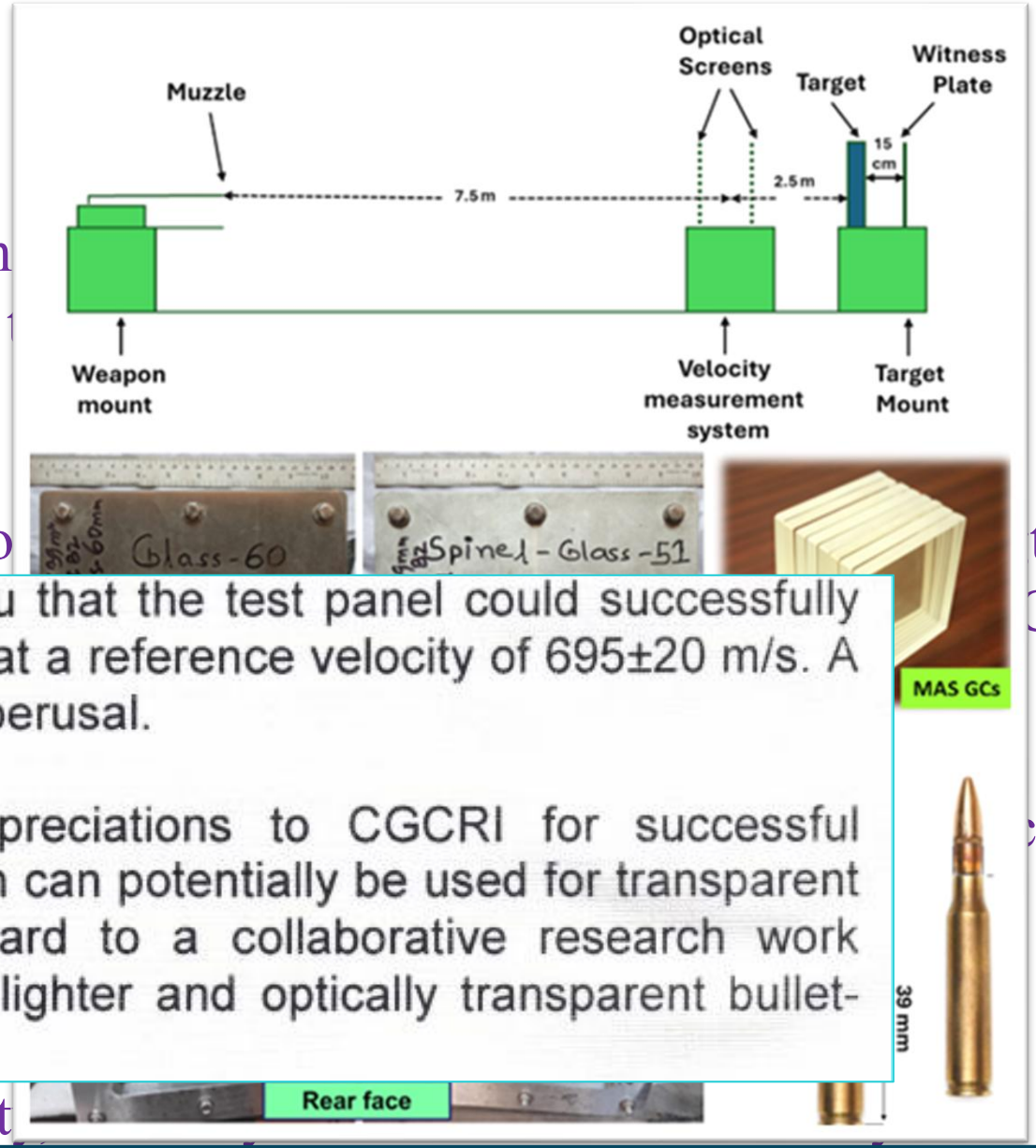
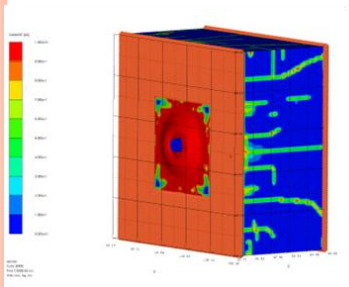


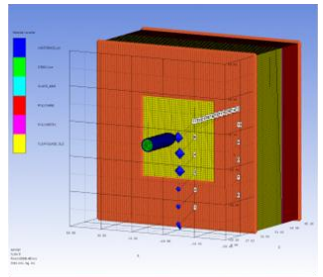
The GCs armour resisted a single bullet 7.62 mm x 39 mm API BZ shot from an AK-47 rifle at a speed of about 700 m/sec from a distance of 10 meters as per NIJ level III, USA specification

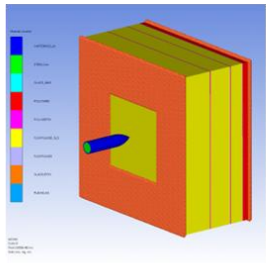
SUMMARY OF KEY RESULTS / ACHIEVEMENTS

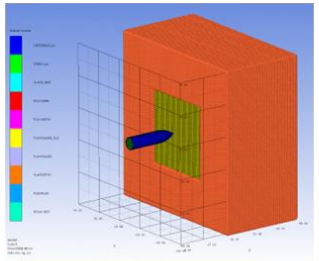
Glass-ceramic based armor test panels deign

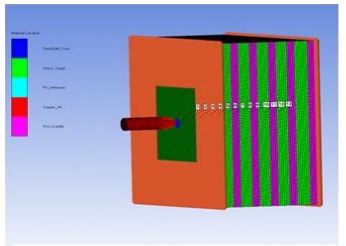
Numerical simulations on layered targets for arriving at best configuration

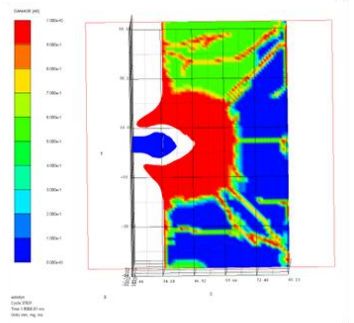


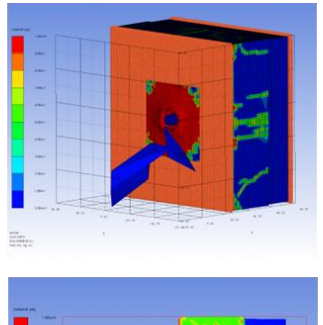


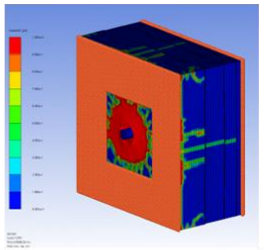


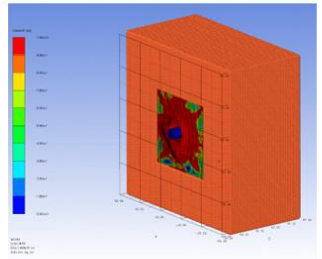


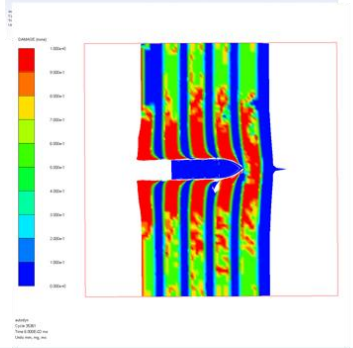


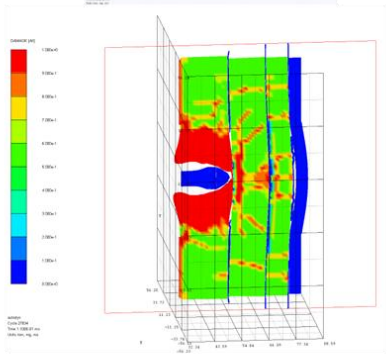


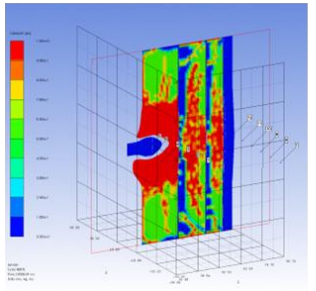












Impact velocity = 865 m/s
Deformable and rigid projectile

Observations:
- Boundary condition
- Layering thickness and sequence
- Projectile type

Monolithic

With fixed BCs at front and back face and for deformable projectile

Two layered

4-layered with PU bond

With two face and all faces fixed BCs at front and back face and for deformable projectile

10-layers SLS/PU layers

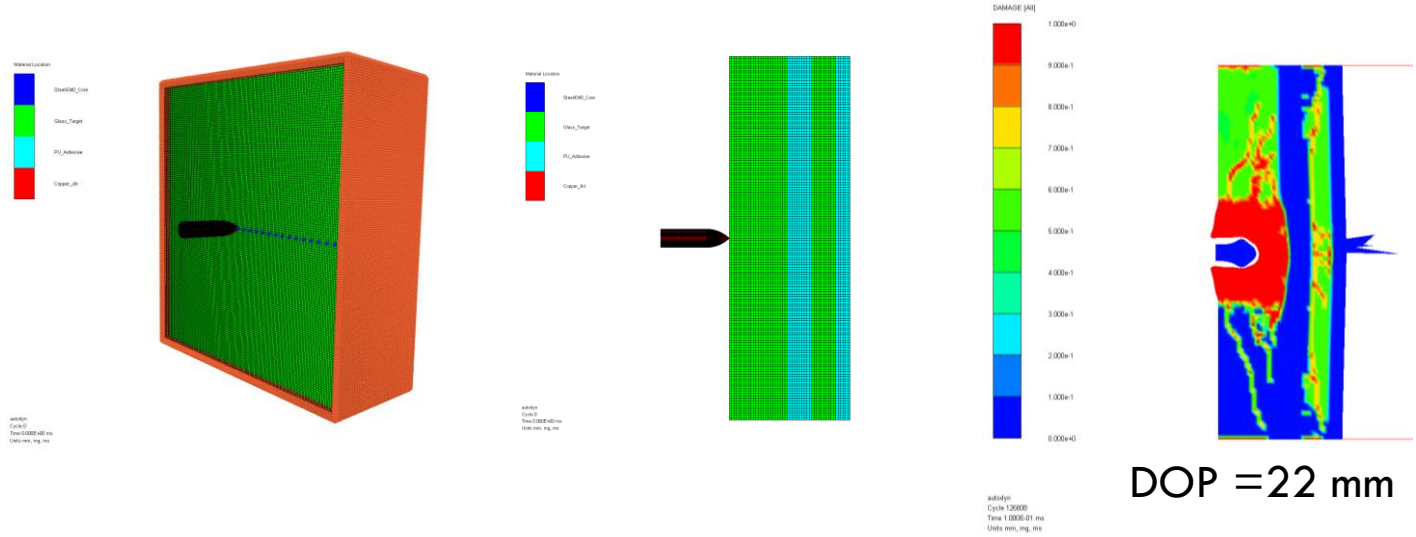
With two face fixed and rigid projectil

Finite Element (FE) Analysis were performed using AUTODYN and ABAQUS to design and study the ballistic performance of transparent glass-ceramic armor panels under 7.62 mm AP projectile impact (~850 m/s), targeting NIJ Level III protection with reduced areal density at CSIR-SERC.

SUMMARY OF KEY RESULTS / ACHIEVEMENTS

Ballistic impact on layered target:

Layer details: **30 mm (glass)-10mm(PU)-10mm(glass)-6mm (PU)**



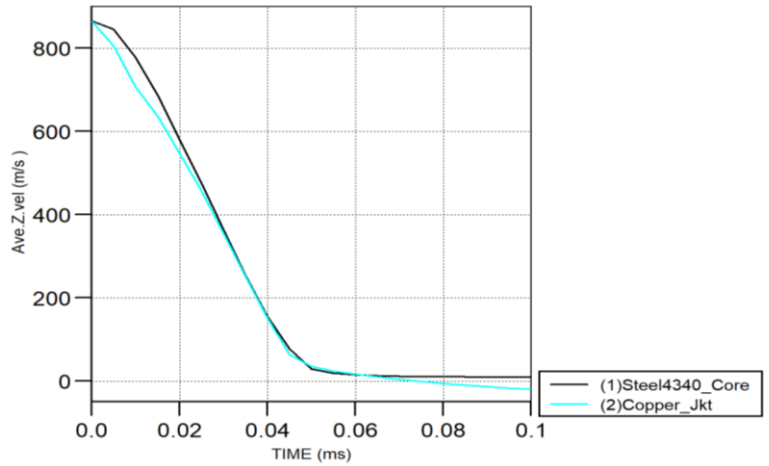
DOP =22 mm

Glass-Polyurethane (PU) Composite panel

Target Size: 150mmx150mmx 51 mm

Projectile:7.62 AP (Mass 8g and velocity impact velocity 850±15m/s)

Boundary condition: All lateral face fixed



Summary on the numerical simulations works

- Numerical simulations have been carried out for designing lightweight transparent armor panels for resisting ballistic impact of NIJ level III.
- Armor Piercing (AP) projectile with steel core of calibre 7.62 mm × 51 mm and impact velocity 850 ± 15 m/s is considered.
- Suitable armor panel configuration is designed using numerical investigations on ballistic performance considering various layer arrangements, boundary conditions and same was sent to CSIR-CGCRI for ballistic impact testing.
- Based on the available material and geometry inputs it was found that about 37% reduction in areal density is possible with MAS glass composite [as layered configuration with [**Polyurethane (bond) – Polycarbonate (backing)]** as compared to soda lime silicate glass.
- Further update in configuration will be made based on ballistic experiment response of proposed armor panel

SUMMARY OF KEY RESULTS / ACHIEVEMENTS

SSNMR EXPERIMENTAL DETAILS

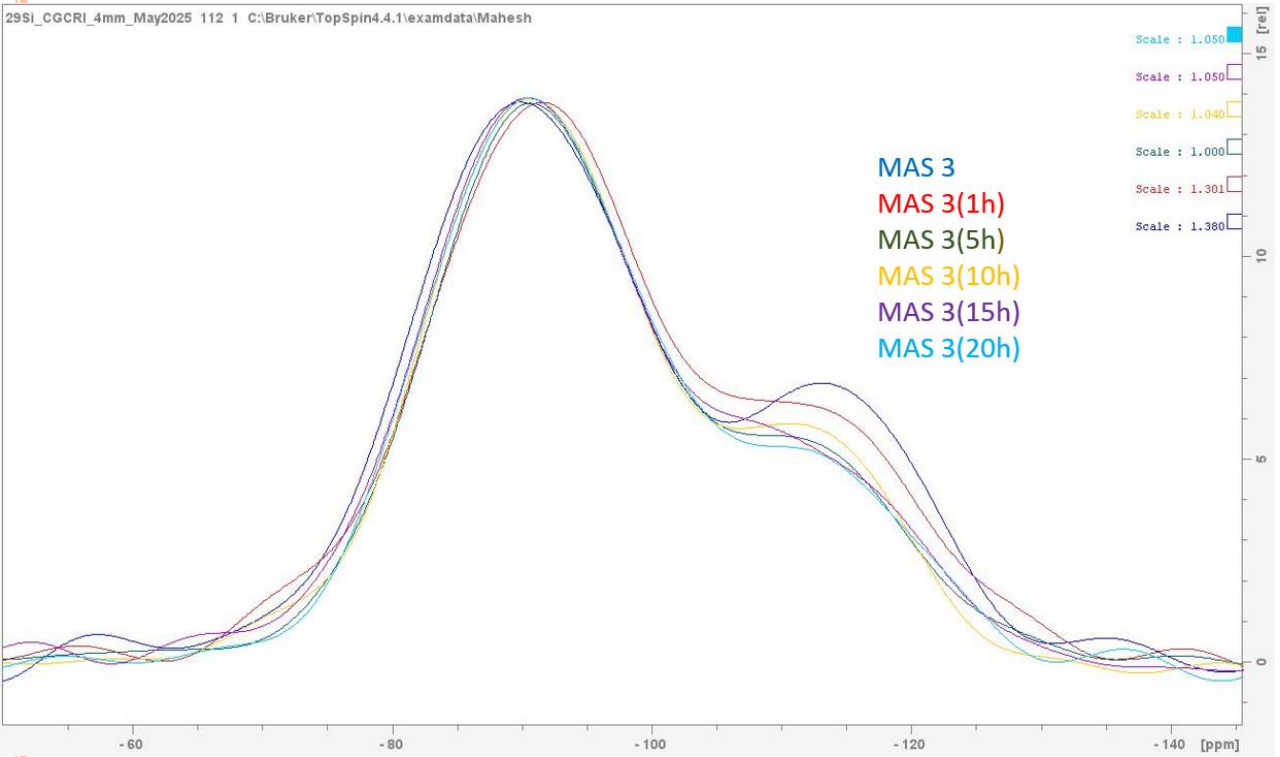
Glass Code	^{27}Al MAS	^{29}Si MAS	^{31}P MAS	^{7}Li MAS
MAS 3 BG	✓	✓	✓	✓
MAS 3 (1h)	✓	✓	✓	✓
MAS 3 (5h)	✓	✓	✓	✓
MAS 3 (10h)	✓	✓	✓	✓
MAS 3 (15h)	✓	✓	✓	✓
MAS 3 (20h)	✓	✓	✓	✓
LAS 3 BG	✓	✓	✓	✓
LAS 3 (1h)	✓	✓	✓	✓
LAS 3 (5h)	✓	✓	✓	✓
LAS 3 (10h)	✓	✓	✓	✓
LAS 3 (24h)	✓	To be performed	✓	✓

MAS NMR study from CSIR-NCL

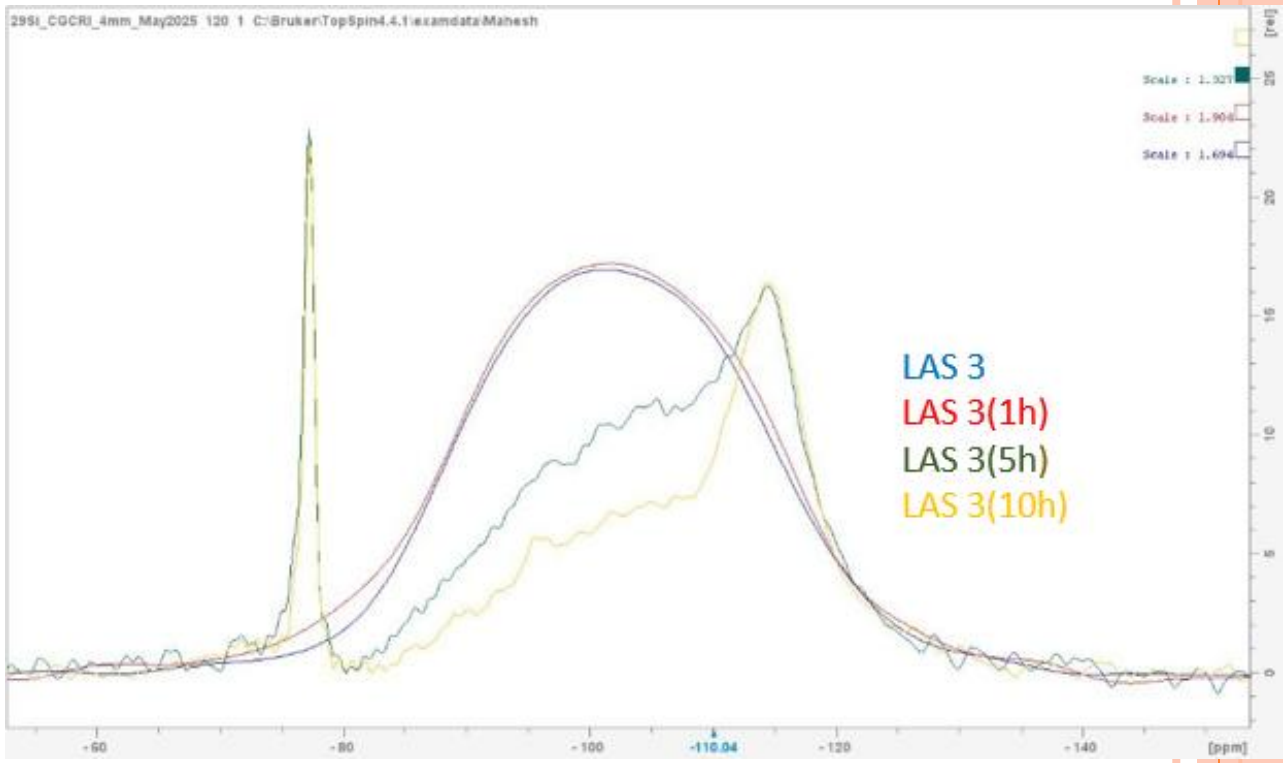
- ^{27}Al and ^{7}Li MAS NMR experiments were recorded at 16.4 T(Bruker AV700MHz) using 1.3mm probe at 40KHz
- ^{29}Si MAS NMR experiments were recorded at 16.4 using 4mm probe at 12KHz
- ^{31}P MAS NMR experiments were recorded at 11.7 T(Bruker AV500MHz) using 4mm probe at 14KHz

^{29}Si MAS NMR

MAS 3 samples



LAS 3 samples

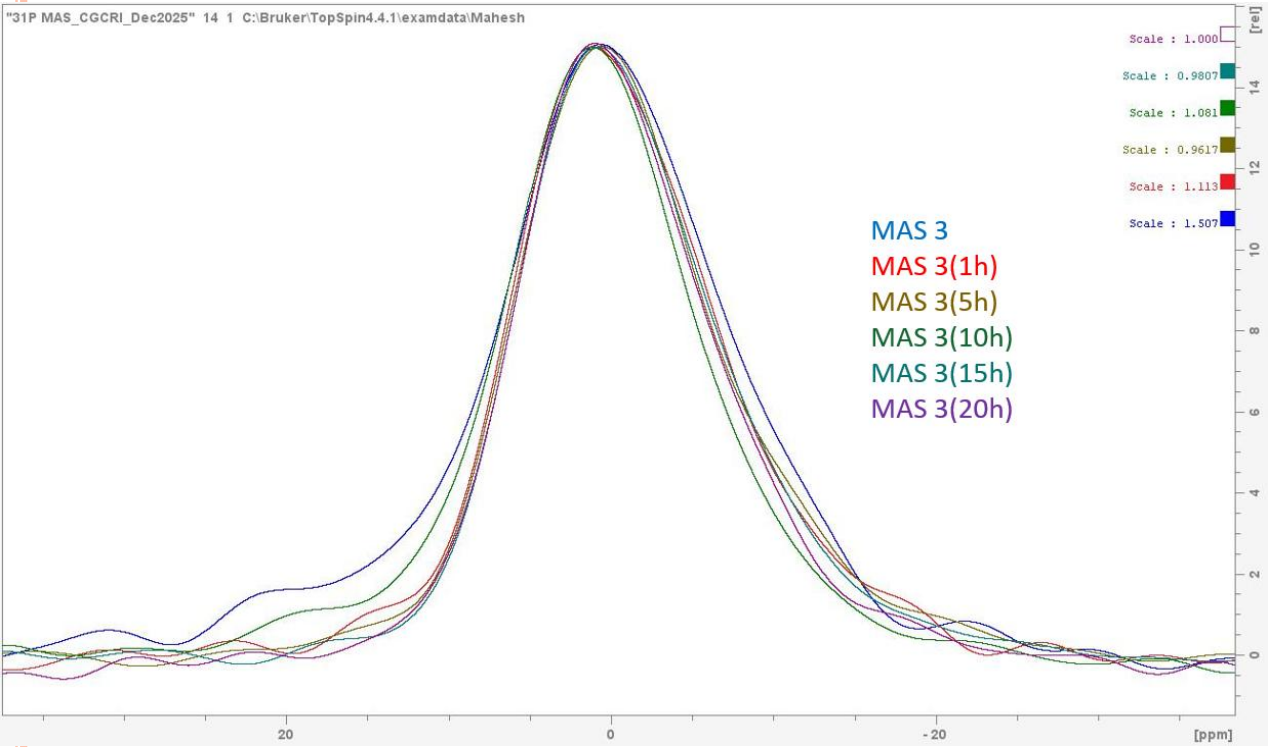


^{29}Si MAS NMR results revealed that

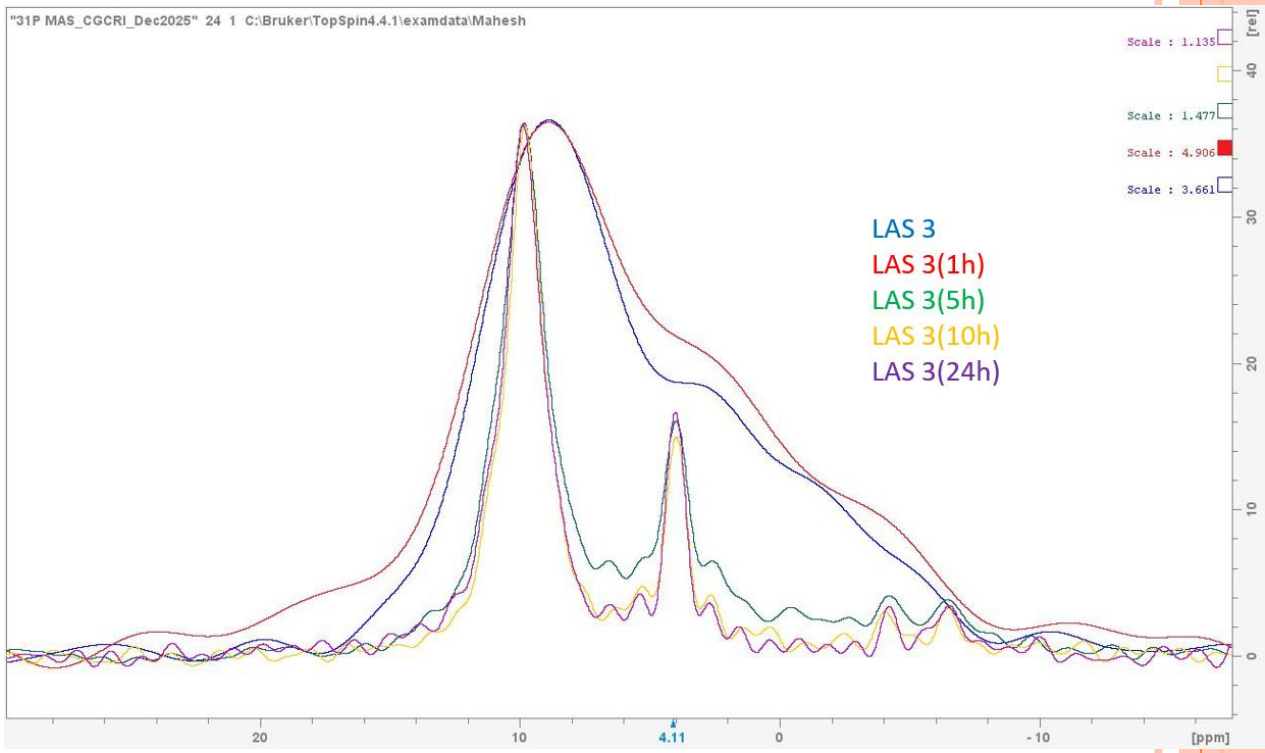
- **Except LAS 3 BG and LAS 3(1h) all the other glasses have both crystalline and amorphous phases**
- **As the heating time increases, crystalline phases become dominant**

^{31}P MAS NMR

MAS 3 samples



LAS 3 samples

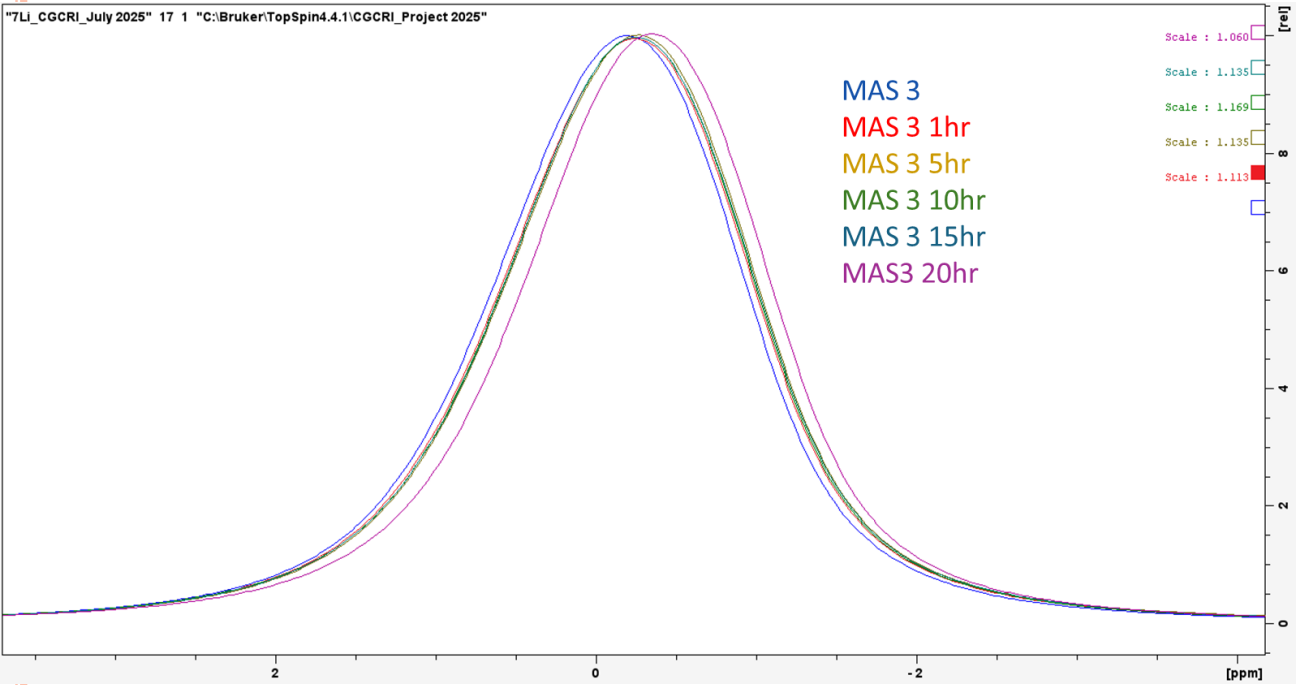


^{31}P MAS NMR results revealed that

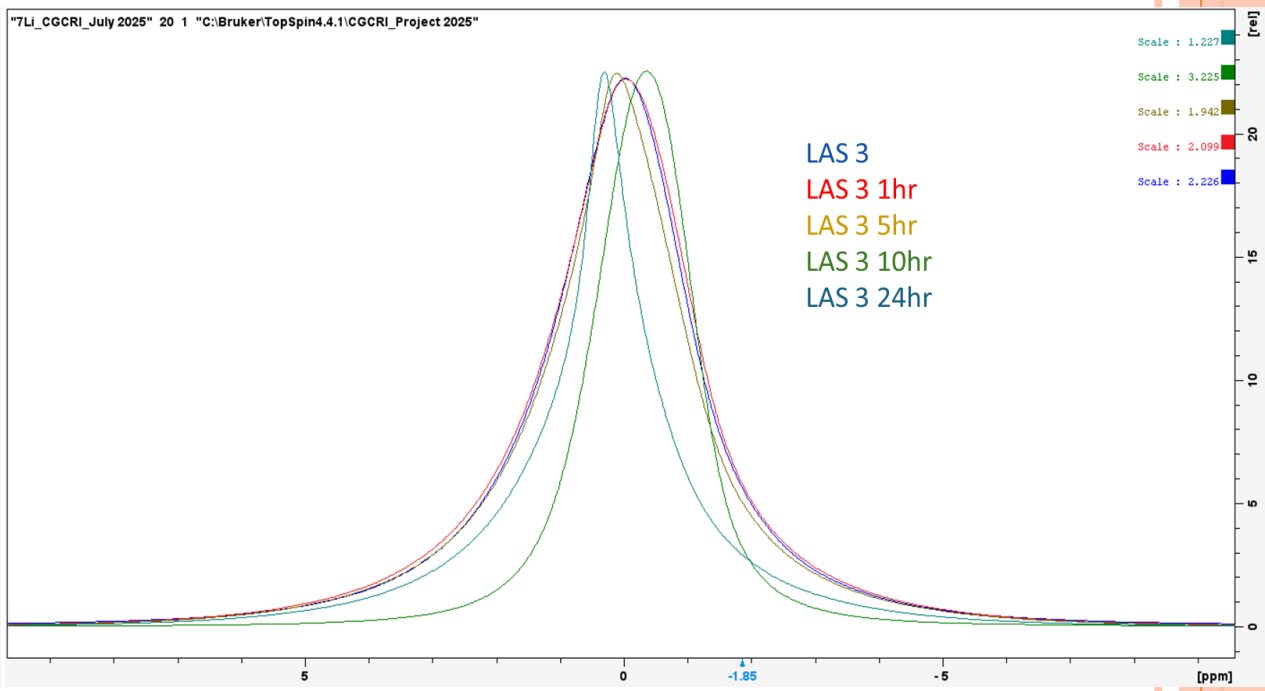
- **Except LAS 3 BG and LAS 3(1h) all the other glasses have both crystalline and amorphous phases**
- **As the heating time increases, crystalline phases become dominant, with LAS 3 (24h) has the prominent crystallization**

^{7}Li MAS NMR

MAS 3 samples

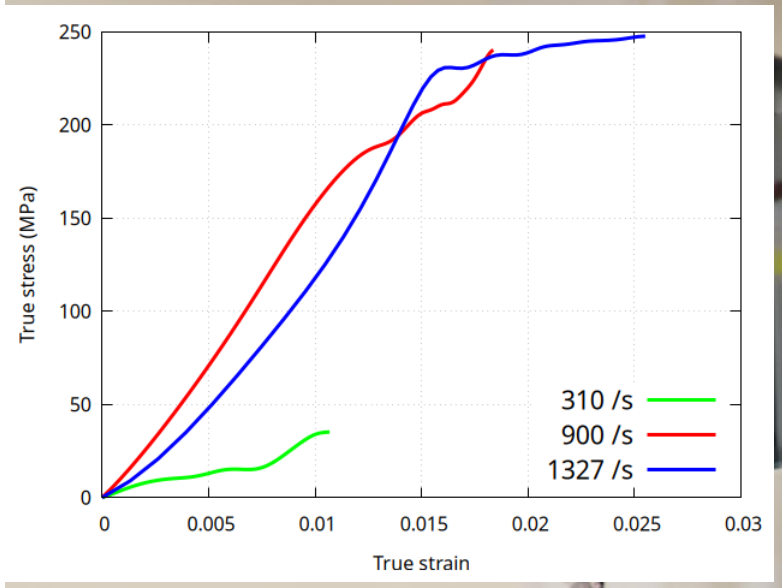


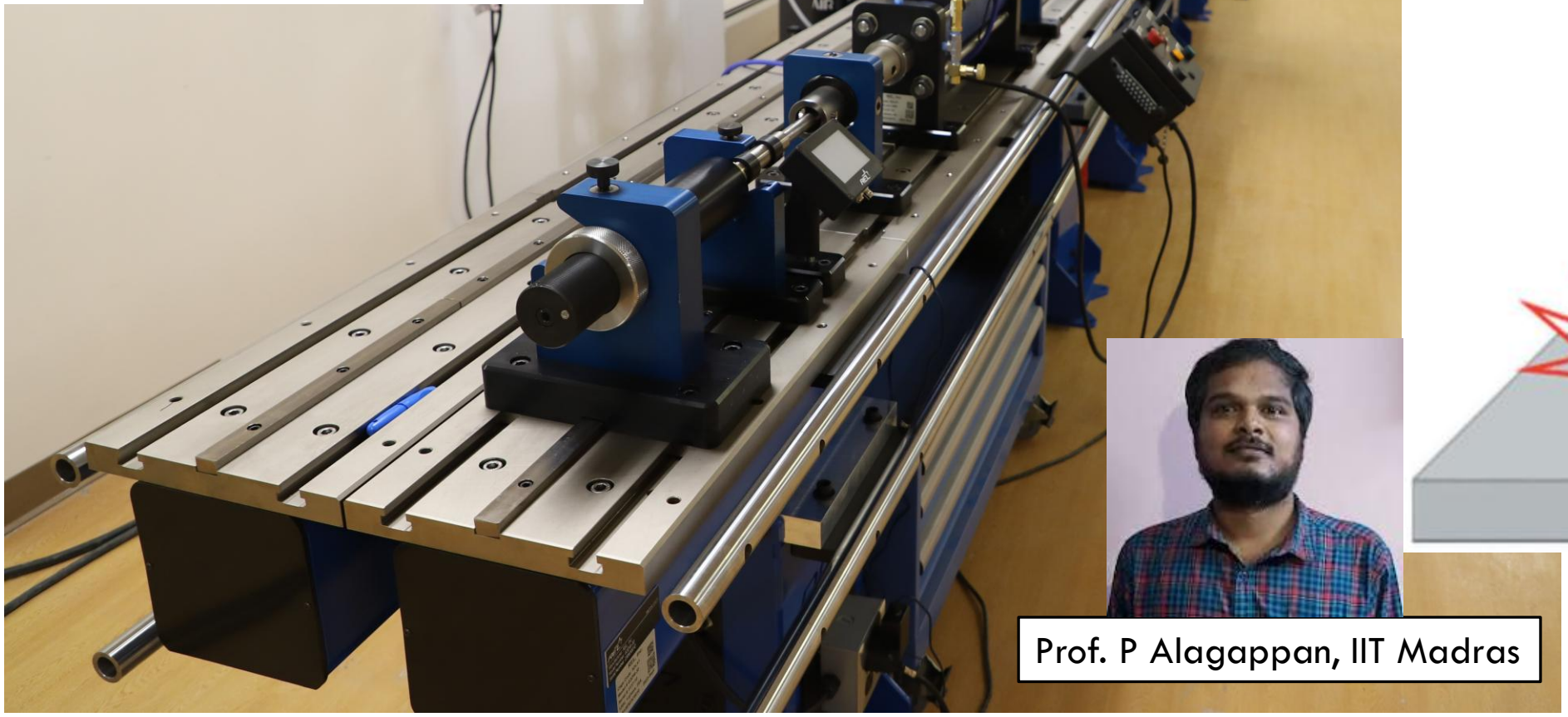
LAS 3 samples



^{7}Li MAS NMR results revealed that

- Center of gravity in MAS 3 series is shifted towards lower ppm may be due to the change in the role of Lithium.
- The change in the peak width of the LAS 3 glasses is due to the crystalline phases





Prof. P Alagappan, IIT Madras