Power Packages Interconnections for High Reliability Automotive Applications

Michele Calabretta
ADG R&D
STMicroelectornics, Italy
michele.calabretta@st.com

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Outline

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Automotive challenges

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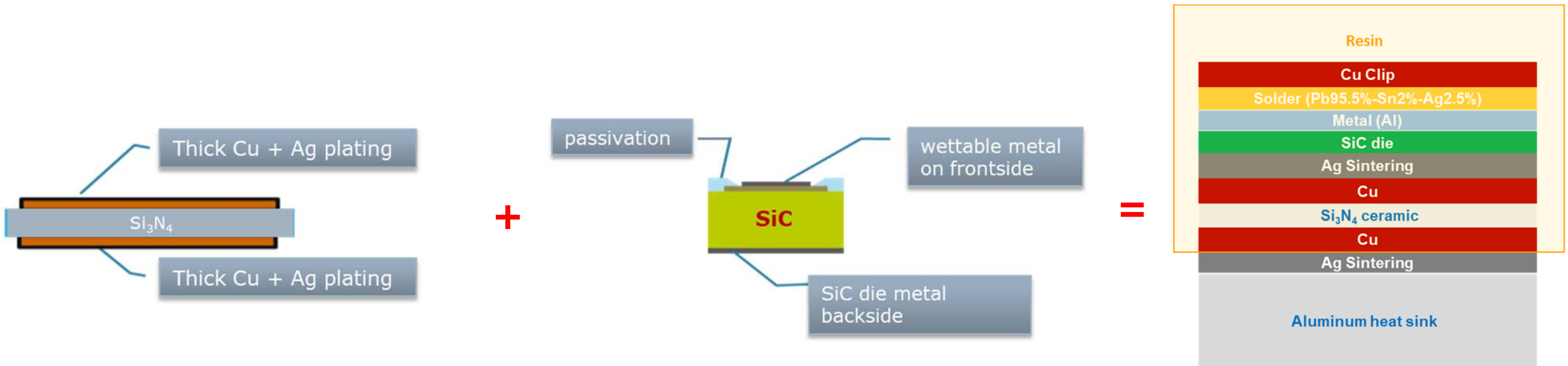
- The compliance with standard normative (e.g., AEC-Q101) could not be sufficient to guarantee reliable products because the requirements are becoming more and more stringent.
- Silicon Carbide (SiC) devices have been recently explored.
- Due to EV/HEV diffusion, electric components are becoming more and more crucial for automotive market.
- Some applications, e.g. *electric control unit* and *traction inverter*, need higher ambient temperatures and longer lifetime requirements, improving at the same time the overall efficiency.

Constrains for WBG

- SiC compounded devices permit to increase the maximum operative temperature more than 200 °C.
- Indeed, the die attach materials have to be able to operate at this temperature.
  - *Ag sintering* technology represents a reliable alternative to soft solder in high temperature and high power density applications (as *automotive ones*).
- In the presented work, Ag sintering pressure-assisted layer has been investigated when submitted to fast transient thermomechanical stress for lifetime estimation on automotive packages.

Test vehicle

SiC Power MOSFET 250A – 650V

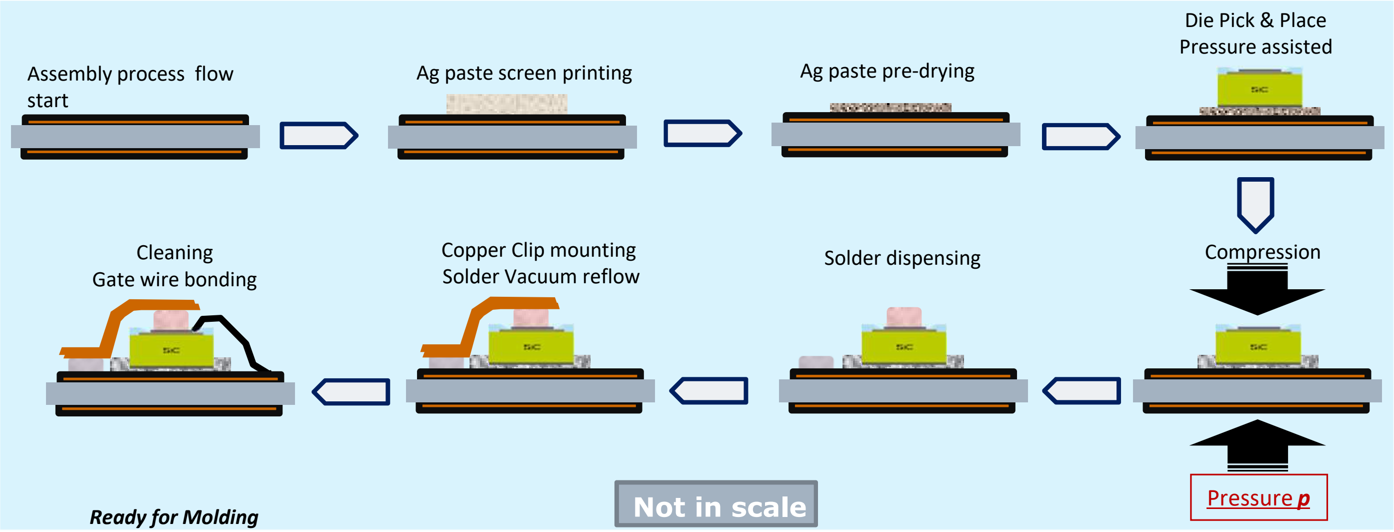


Simplified vertical structure of a standard device assembled on the module

- Considered test vehicles are SiC devices (250A, 650V) sintered by Ag pressure assisted process on AMB substrate and assembled in molded discrete package

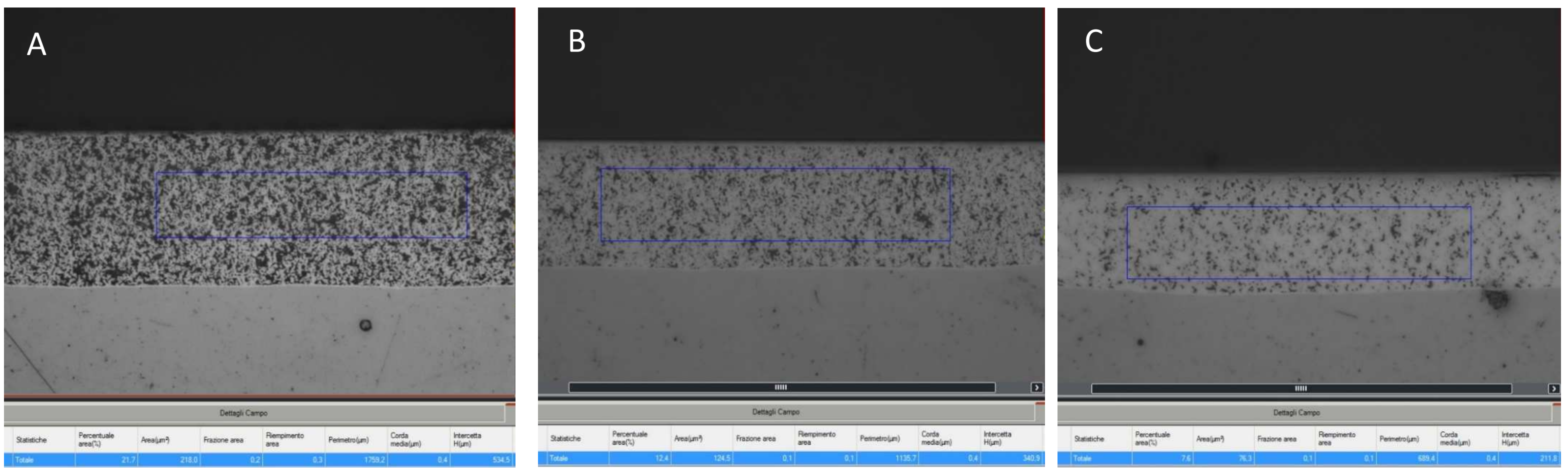
Ag Sintering pressure-assisted and clip soldering flow

The aim of activity has been to optimize the pressure p used during compression phase.



Experimental results

Ag sintering pressure-assisted layer has been investigated at time zero before submitting to fast transient thermomechanical stress ($\Delta T/\Delta t$ ~500K/min) for lifetime estimation on automotive packages.



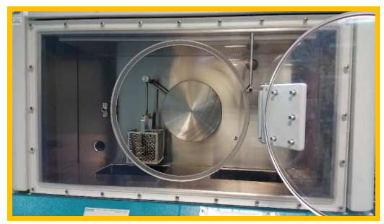
Average porosity: 21.7%

Average porosity: 12.4%

Average porosity: 7.6%

Layers sintered using respectively pressure A, pressure B and pressure C (with A<B<C)

Thermal Shock chamber



Equipment detail (moving basket)

THERMAL SHOCK CHAMBER FEATURES		
Equipment name	:	CSTL 12
Brand name	:	ACS
Operative conditions	:	-65 °C/+175 ° C
Frequency	:	3 min hot / 3 min cold
Moving basket capacity	:	1.7 l
Nr. Shocks/min	:	1sh/6min
Stress ambient	**:**	**Liquid-to-Liquid**
Total Liquid Volume	:	45 l
Liquid	:	PFPE - perfluoropolyether fluid (Galden D02TS)
Density (@ 25 °C)	:	1.7 g/cm^3

- The stress is provided by thermal shocks in liquid-to-liquid ambient (PFPE - perfluoropolyether fluid) using temperature range of -65 °C/+175 °C (3min cold/3min hot, 6min/cy).

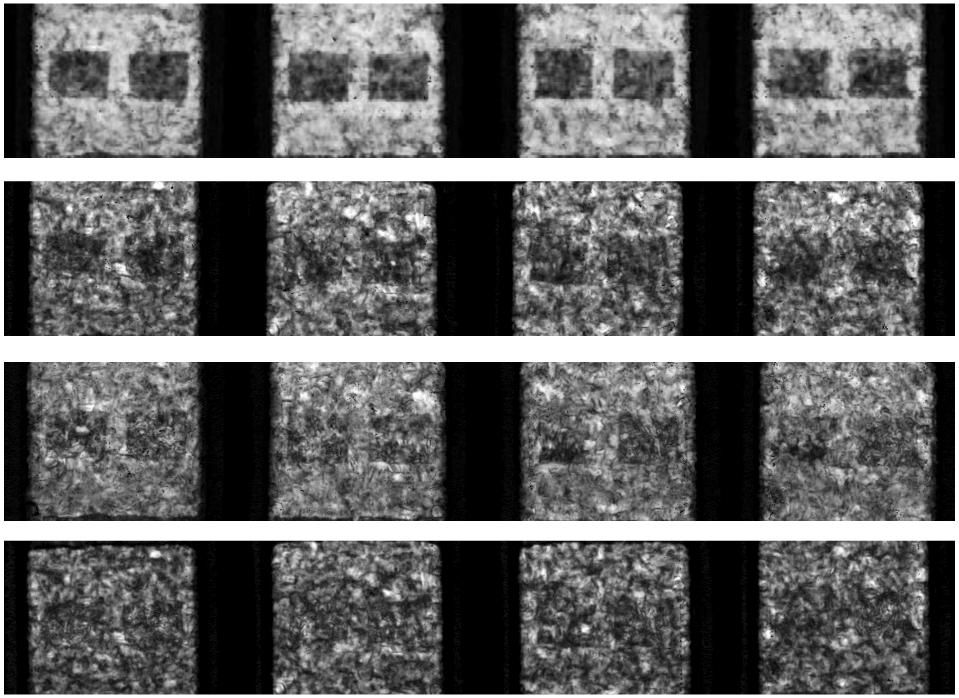
C-SAM Analysis on package backside (pressure C)

t_0

1000 sh

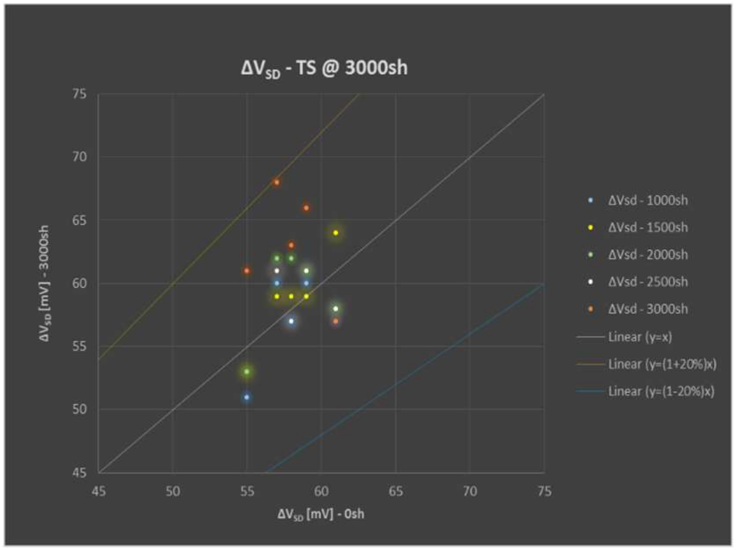
2000 sh

3000 sh



C-SAM analysis on package backside shows the Ag sintering layer degradation induced by thermal shocks.

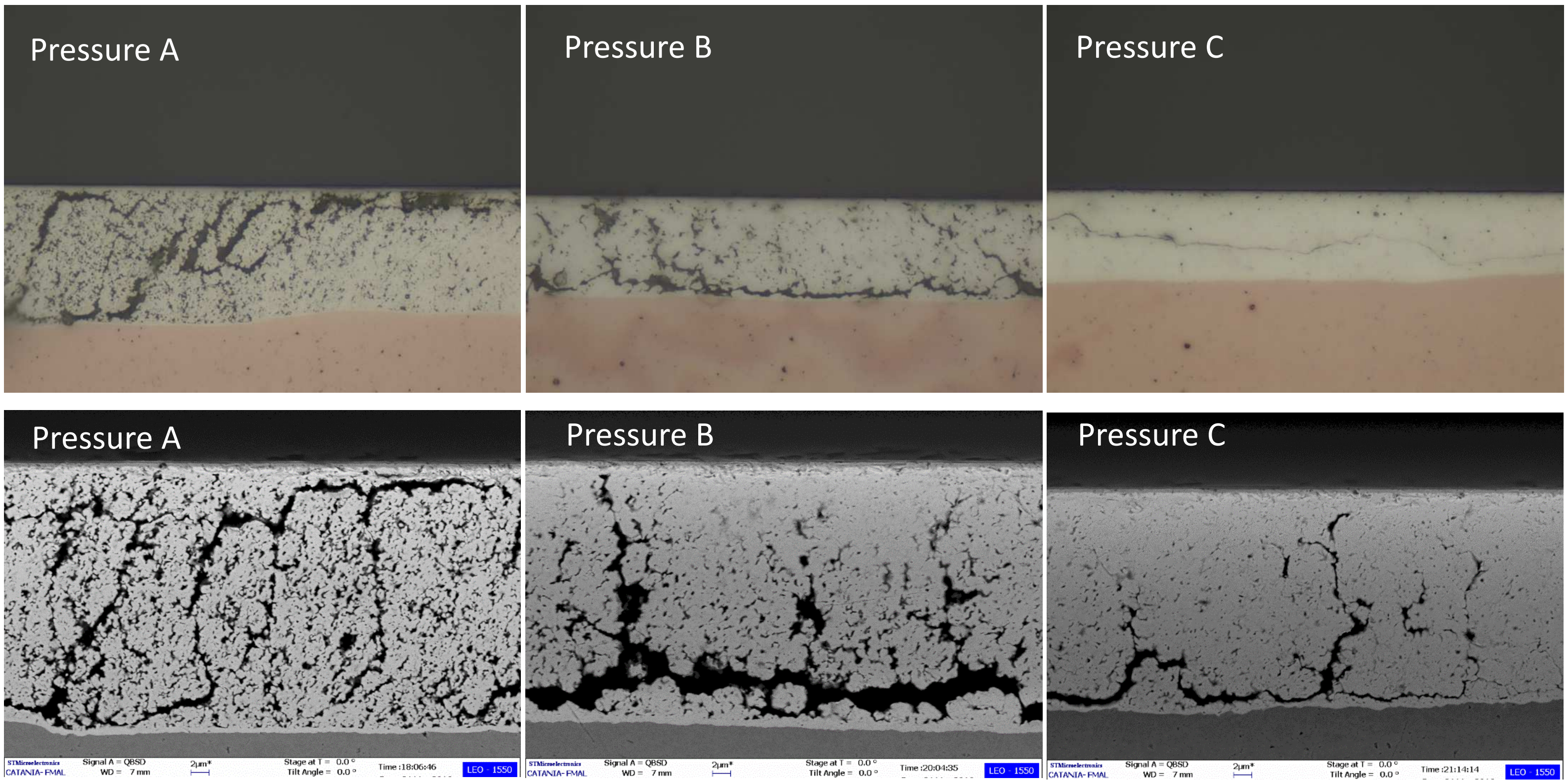
ΔV_{SD} Drift analysis



EQUIPMENT FEATURES		
Equipment name	:	9214-KT/9215-PUL ΔVBE/ΔVDS/ΔV_F TESTER
Brand name	:	TESEC
Forcing Current range	:	0.01 ÷ 40A
Operative conditions	:	200V/40A
Sensing Current range	:	0.001 ÷ 100mA
Gate limit voltage range	:	1 ÷ 20V
Power Dissipation time range	:	300µsec ÷ 9.99sec
Delay Time range	:	10 ÷ 999µsec
VCB/VDS	:	1 ÷ 200V

ΔV_{SD} drift during TS confirms the sintering degradation

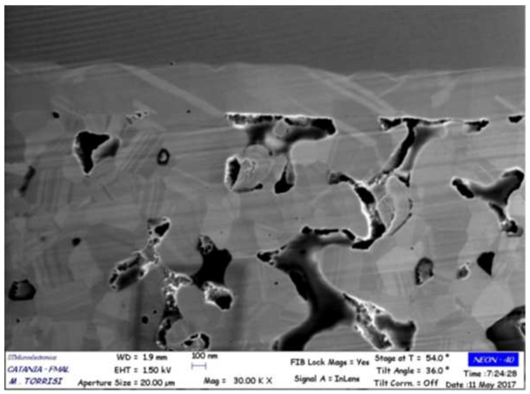
Metallographic cross-section and SEM analysis after 3000 TS



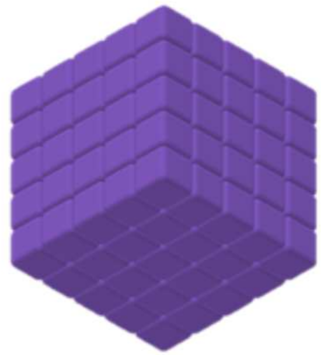
- Analyses demonstrate more aggregate Ag particles improve the Ag sintering reliability

CAD/FEM Modelling: *Material Virtual Characterization*

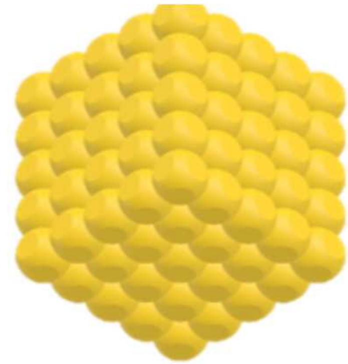
(a)



(b)

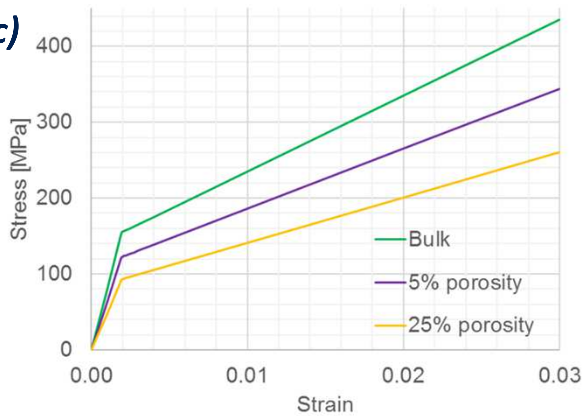


(a) Porosity 5%



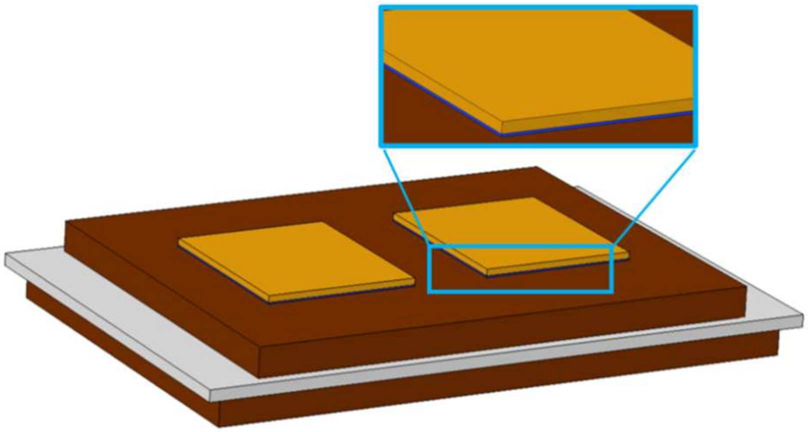
(b) Porosity 25%

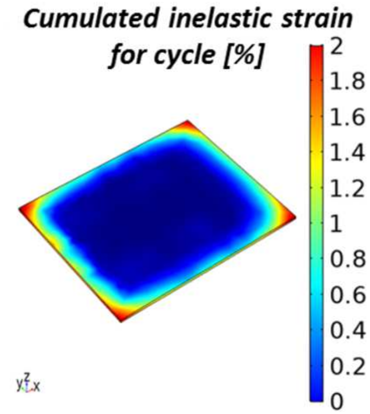
(c)



Starting morphological analysis of microstructure texture ***(a)***, a cell models ***(b)*** has been developed for mechanical properties simulation at different porosities ***(c)***.
For pure Ag an initial yield strength of 160 MPa at RT was taken from literature published data and true-stress/true strain measurements done in house on dogbone Ag sintering samples.

FEM Modelling:
Thermal Shocks simulation





Porosity %	Cumulated plastic strain $\Delta\varepsilon_{cycle}$	Cycles to failures N_F
8	1.27%	5000
20	1.75%	3000

The matching between simulation results and experimental data have been done using as End of Life Criteria (EOL) the maximum degradation area, detected by SAM analysis over 20% of total sintering area.

Starting from data reported in table, it is possible to derive coefficients a and m for Coffin-Manson equation

$$N_F = a \cdot \Delta\varepsilon_{cycle}{}^{m}$$

whereas ***a*** and ***m*** are equal respectively to 3.34 and -1.67

Conclusions

- The setup of a pressure-assisted silver sintering process has been performed by means of an experimental methodology, made by different microscopic and electric analyses.
- Thermal Shocks could be taken into account as alternative practice to estimate lifetime in shorter times and with higher capacity than other active thermomechanical stress tests.
- An integrated approach using CAD and FEM has been used to characterize the sintering material and to reproduce the aging effect produced by a fast transient strain rate transformation like Thermal Shock Test conditions.
- A lifetime model correlating experimental results in terms of sintering area delamination with simulated cumulative inelastic strain has been used as predictive methodology for reliability forecast of power device automotive applications.

Key References

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Thank you
for your attention

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M. Calabretta; M. Renna; V. Vinciguerra; A.A. Messina
michele.calabretta@st.com

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