Ni-Al film multilayer structure effect on melting threshold and melt thickness in Ni-Al surface alloy forming process

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Introduction

Coatings are used to change surface properties for a long time and are widespread in industrial technologies. The weakness of the coatings is the insufficiently reliable adhesion of the coating to the treated surface. It can be avoided by forming surface alloy at the surface since it has no sharp boundary. Surface alloy forming process comprises two successive steps. First, surface alloy components thin film layer or several layers are deposited alternately. The materials proportion in the surface alloy chemical composition determines the thicknesses and number of layers to be deposited. Second, the multilayered structure is exposed to a low-energy, high-current electron beam (LEHCEB) treatment which induces deposited multilayered structure and substrate liquid-phase mixing.

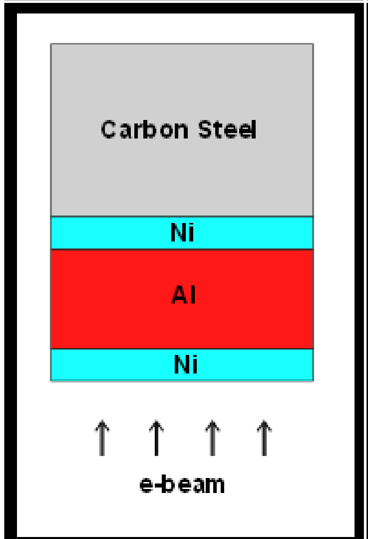
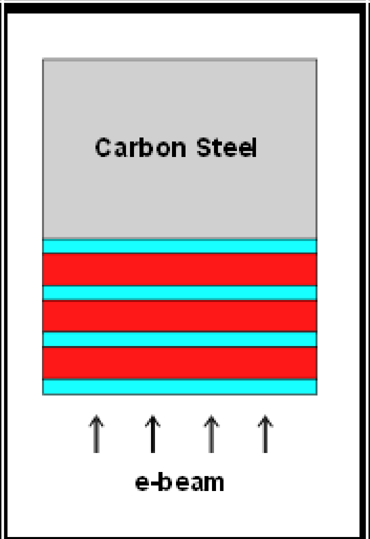
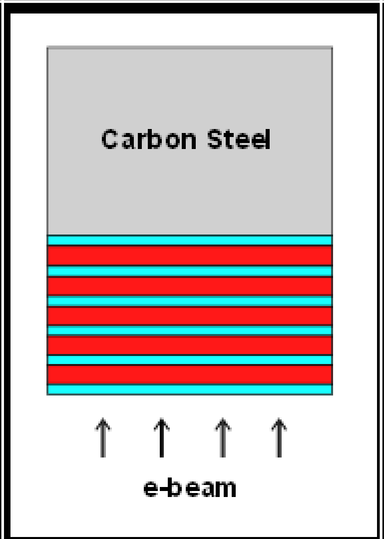
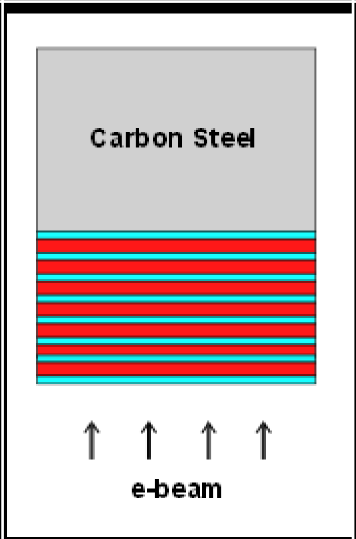
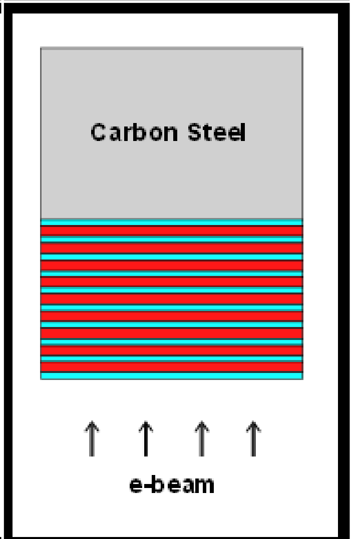
As it mentioned above surface alloys with complex chemical composition are formed by multilayered systems. Multilayered structure components thermal parameters ratios can affect on near-surface region thermal regime.

Work purpose

Present work purpose was to receive dependences between thermal regime characteristics (temperature field, melting threshold, melt thickness and melt lifetime)and Ni to Al layers thickness ratio. Another purpose is to determine if there are some **effective multilayered structure** layers thicknesses at which the **melting threshold is minimal**.

Modeling and results

The calculations were carried out for five of Ni-Al multi-layered structure types

1	2	3	4	5
				
Ni – 0.5 мкм	**Ni – 0.25 мкм**	**Ni – 0.167 мкм**	**Ni – 0.125 мкм**	**Ni – 0.1 мкм**
Al – 1.5 мкм	**Al – 0.5 мкм**	**Al – 0.3 мкм**	**Al – 0.214 мкм**	**Al – 0.167 мкм**

Properties of materials

	Thermal property	Material		
		Al	Ni	Carbon steel
density	ρ, kg/m^3	2700	8600	7850
heat capasity	c, J/(kg K) (at 300 K)	902.5	439	460
heat conduction	k, W/(m K) (at 300 K)	237	64	56
melting point	T_m, K	933.3	1726	1600
latent heat of melting	L_m, kJ/kg	396.6	303.2	205

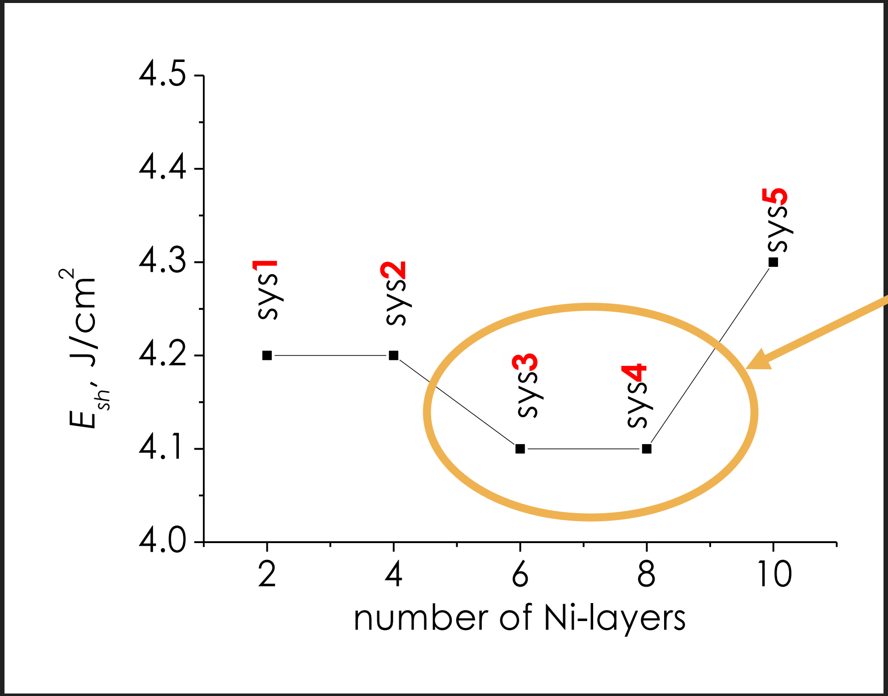
carbon steel (0.14-0.22% C; 0.15-0.3% Si; 0.4-0.65% Mn, 0.3%Ni; 0.3% Cr; Fe – balance, wt.%)

Calculations were carried out for a single pulse with 22 keV electron energy and 2.5 μs duration.

Results: melting thresholds

As a result of calculations it was obtained that melting thresholds of pure Al, Ni and carbon steel are 2.4, 3.8 and 2.1 J/cm^2, respectively.

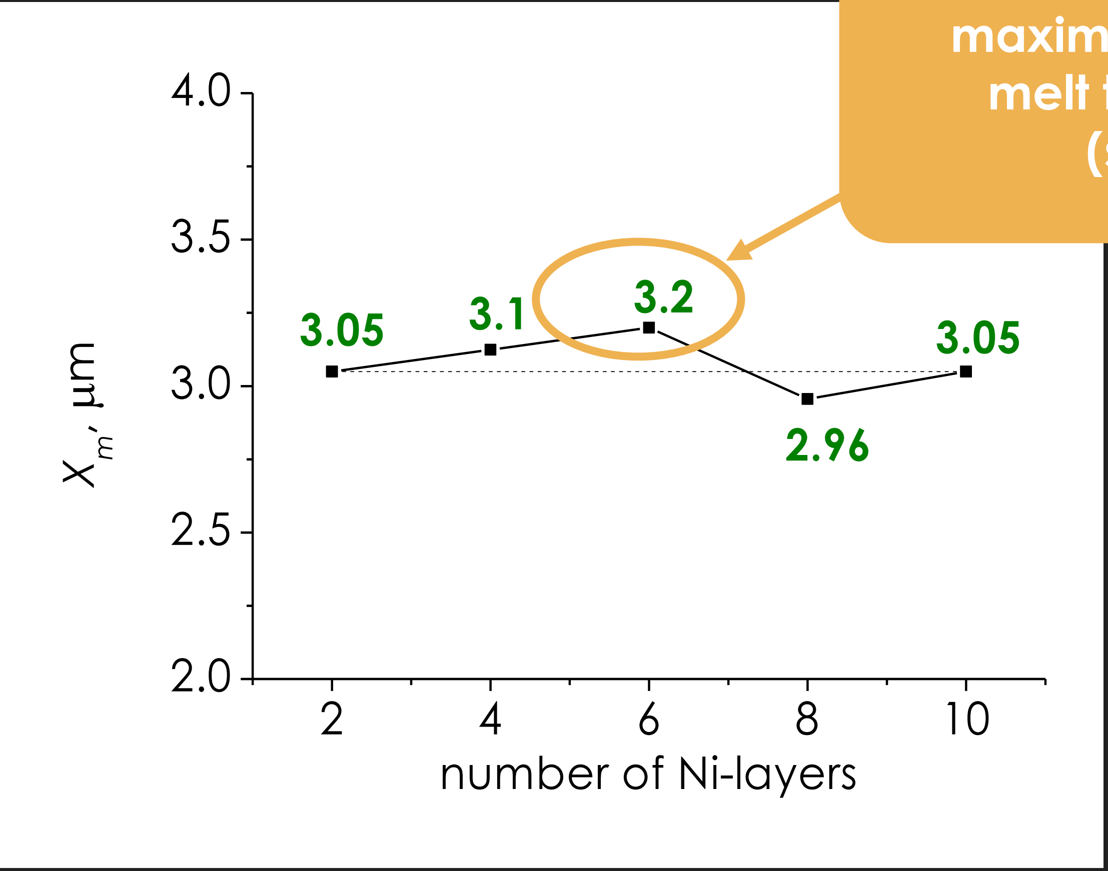
Melting threshold values for five types of multilayered systems



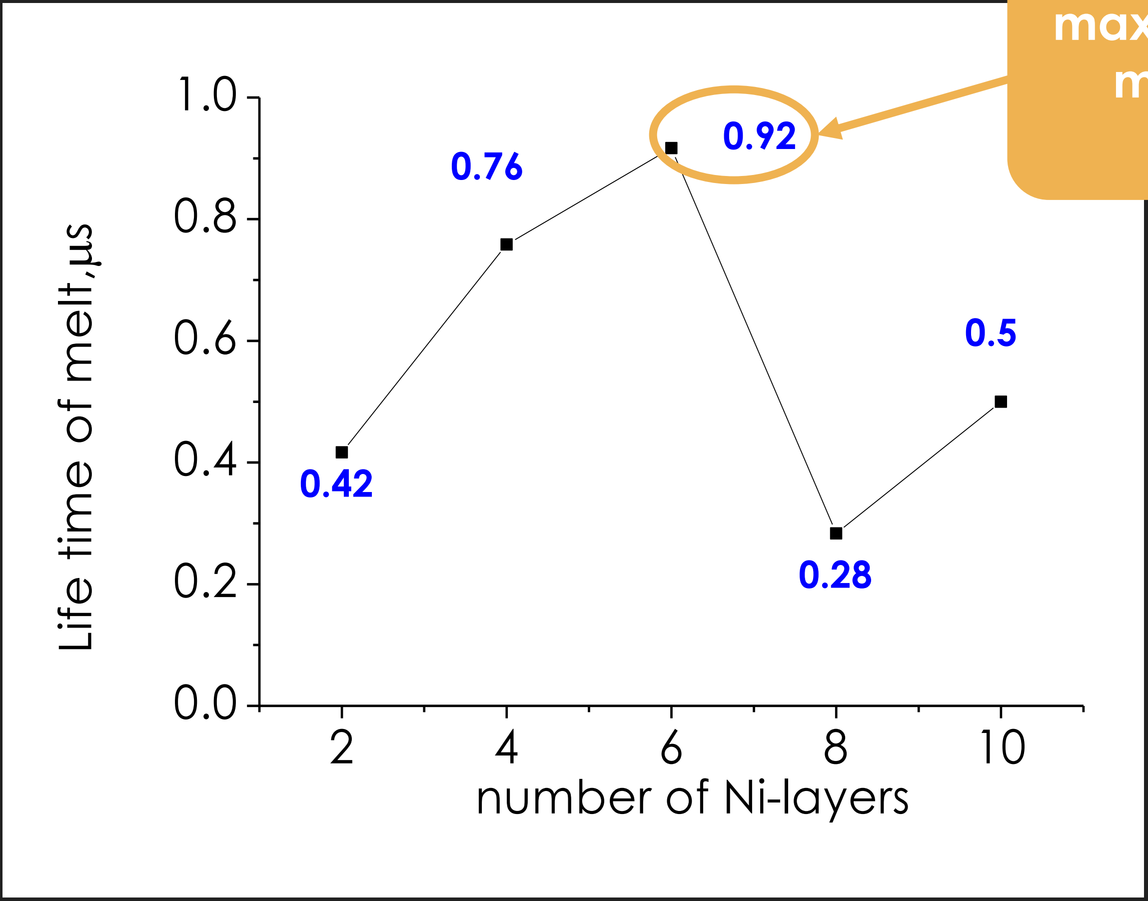
minimal values!

Results: melt thickness

maximal value of melt thickness (sys3)

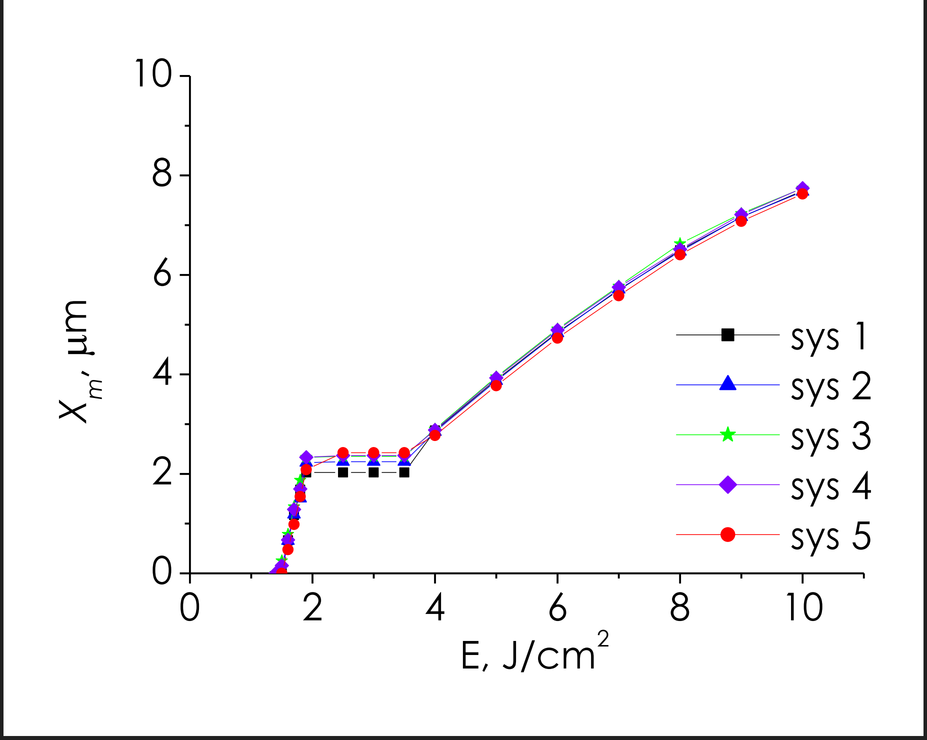


Results: melt lifetime



maximal value of melt lifetime (sys3)

Results: melt thickness dependence of e-beam energy density

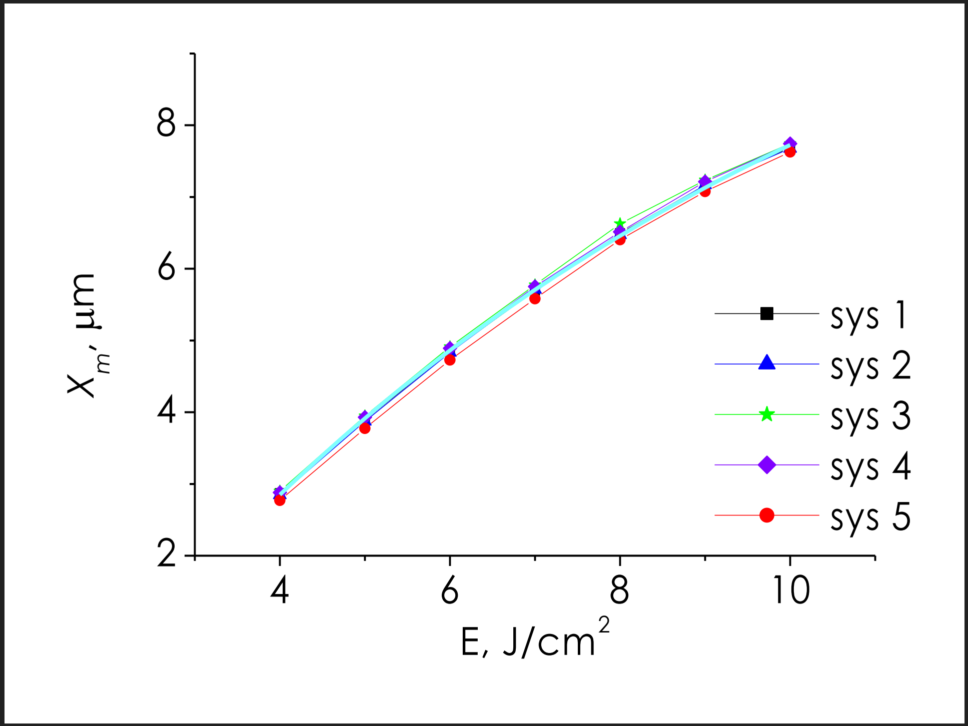


The first portion of melt, in cases of type 1, 2, 5 multilayered systems, appears at energy density of 1.6 J/cm^2, in Al- layer, i.e. beneath the irradiated surface. In cases of systems type 3 and 4, the first portion of melt appears at 1.5 J/cm^2. As energy density increases, the Al-layers are melting one by one and the melt thickness rises. The Ni-layers begin to melt later. At energy density 1.9 – 2.5 J/cm^2, Al-layers are melting completely. Further, the thickness of the melt does not change with the increase in the energy density, the lifetime of the melt grows only.

At 3.5 J/cm^2, the Ni-layer located on the irradiated surface begins to melt, then the melt appears in the substrate material, and finally in the Ni-layer lying close to the substrate.

Results: melt thickness dependence of e-beam energy density

The part of the curve corresponding to beam energy densities greater than 4 J/cm^2 can be described analytically

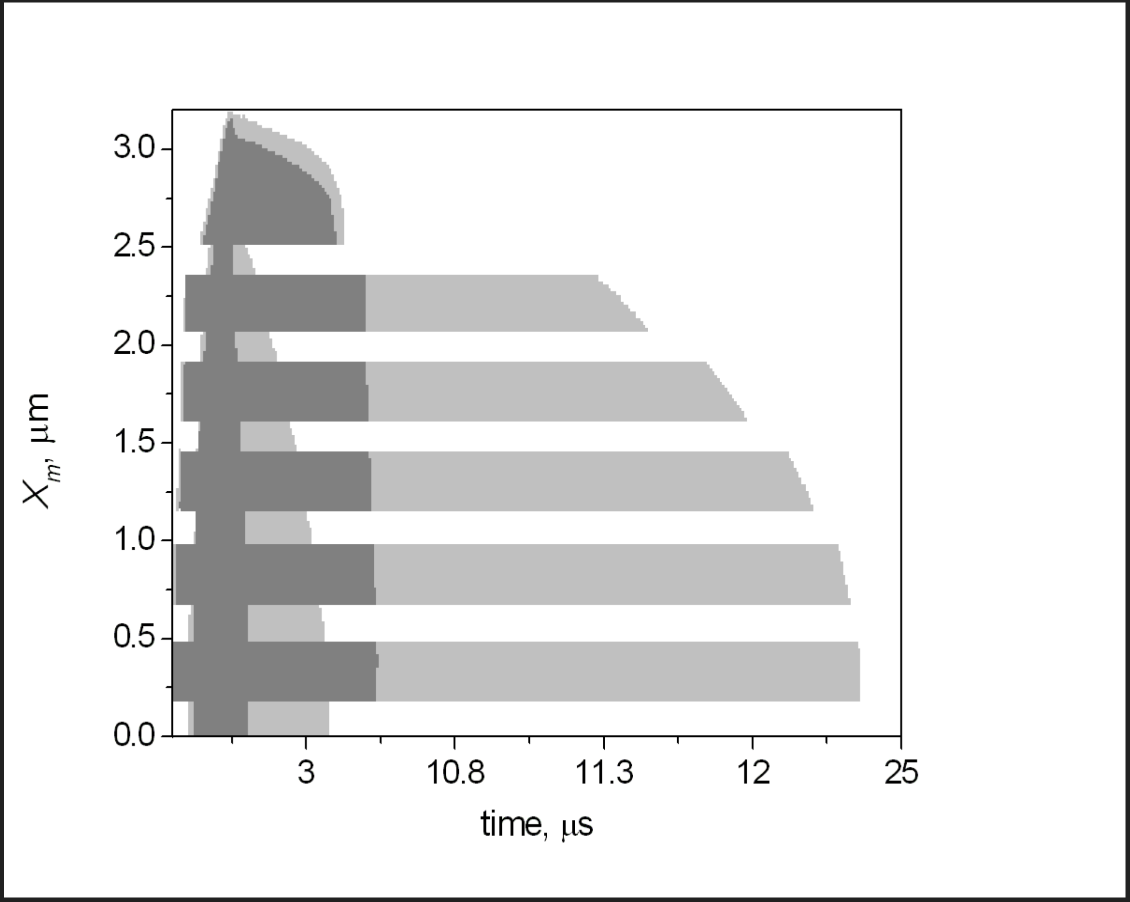


$y = y0 + A*\exp(-E/t1)$

y0	12.59272	±0.59588
A	-15.47594	±0.32986
t1	8.6441	±0.73342

Results: A diagram of the state of a type 3 multilayer system

under irradiation by LEHCEB with an energy density of 4.1 J/cm²



Conclusion

By temperature fields simulation in five multilayered system types, melting thresholds, melt thicknesses and melt lifetimes were obtained. Melting thresholds values for multilayered systems types 1 – 5 are 4.2, 4.2, 4.1, 4.1 and 4.3 J/cm^2, respectively.

No significant influence of the number and layers thickness on thermal conditions was found in the considered multilayer systems.

A preference should probably be given to multilayer systems with an average layers number. Preferred layer thickness should be in range of 5-15% of multilayer structure total thickness to be deposited.

The multilayered system type 3 can be selected as more preferred because of its minimal melting threshold, maximal melt thickness and melt lifetimes values.

Thank you for your attention!