Self-Healing LaB6 Emitters

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Abstract: *Practically all commercial LaB6 cathodes make use of (100) crystalline plane symmetry, stability, and low workfucntion. However, in real gun, this plane may suffer dramatic transformations, including surface damage, partial re-crystallization, etc. We studied self-healing of LaB6 cathodes suffered (100) plane damage.*

Keywords: thermionic emission; LaB6; crystalline planes; re-crystallization; workfunction; emission recovery; e-beam lithography.

Introduction

LaB6 cathode technology has progressed from sintered emitters to single crystal ones. Engineers have unanimously chosen (100) crystalline plane as the emitting surface. It offers 4-fold symmetry, emission with low noise and good stability, and apparently lowest WF of ~2.60 eV. Today's commercial LaB6 cathode loadings run to 10 A/sq.cm and up.

However, as cathode runs, (100) face crystalline beauty may suffer various and sundry damages, caused by partial oxidation, arcing, ion bombardment, etc. Fig.1 depicts LaB6 surface defect caused by arcing

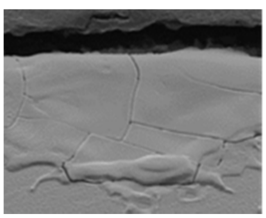

Figure 1. LaB6 surface defect caused by arcing.

LaB6 surface recovery via evaporation

Since LaB6 emission is rather volumetric effect and isn't controlled by a specific surface layer, LaB6 cathode emission is partially or even fully recoverable after system mishaps (pressure rise, contamination, arcing).

Emission recovery happens via surface evaporation with fresh, undamaged (100) plane emerging as damaged material layer goes away.

LaB6 evaporation data are numerous and contradictory. Difficulty being, LaB6 surface readily reacts with H2O, O2, CO/CO2, which affects evaporation rates and congruency. Fig.2 shows incongruent LaB6 evaporation at T < 1950K, i.e. at temperatures where commercial LaB6's operate. If chart in Fig. 2 is correct, then LaB6 evaporation would turn LaB6 into LaB10+ and kill emission very quickly.

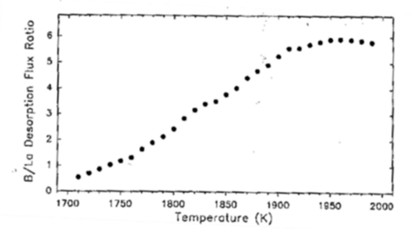

Figure 2. B/La evaporation ratio vs temperature [1].

Evaporation heals volumetric defects?

Work with ternary crystals $Ce_xLa_{1-x}B6$ produced never-seen previously emission defect that most likely had been caused by CeB6/LaB6 lattice mismatch (lattice constants are 4.157 Angstrom for LaB6 and 4.129 for CeB6)

As reported in [2], the emissive surface non-uniformity self-healed in ~300 hrs (Fig.3).

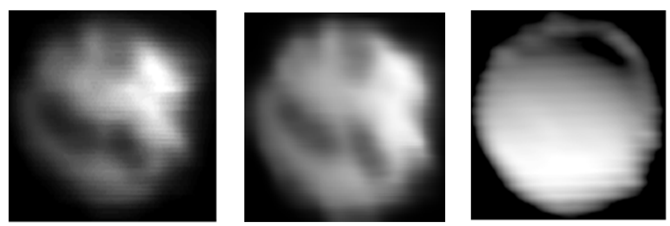

Figure 3. $La_{0.35}Ce_{0.65}B6$ cathode started out with very non-uniform emission surface, which self-healed in 15 days (l-to-r day1>day2>day15)

This crystalline face emission defect was clearly showing in beam cross-section profile (Fig.4).

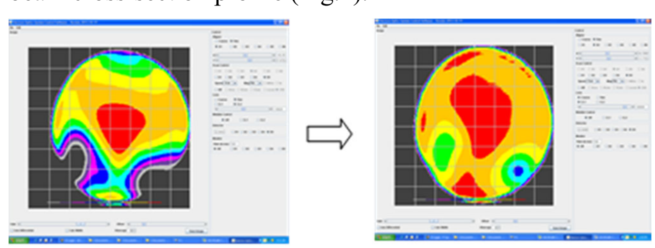

Figure 4. $La_{0.35}Ce_{0.65}B6$ beam cross-section on day 1 (l) and day 15 (r).

Case study: severe damage recovery dynamics

We had several LaB6 emitters intentionally damaged by laser ablation (Fig.5).

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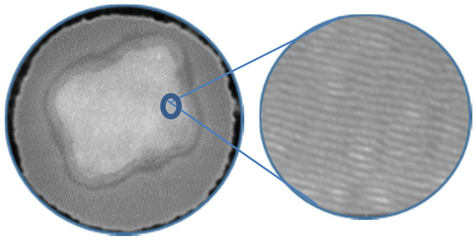

Figure 5. Example of LaB6 surface intentional damage.

LaB6 cathode showed in Fig.5 ran at T~1800K for 15 days, with daily workfunction (WF) and emission image checks.

Fig.6 depicts emission image on day 1:

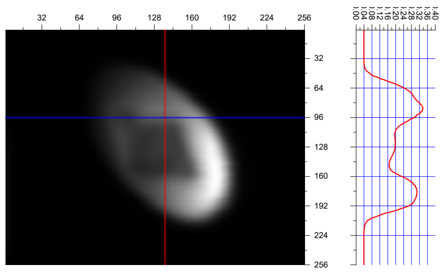

Figure 6. Intentionally damaged LaB6 emission image.

Emission contrast in Fig. 5 reached 1.80X.

This cathode' emission image and WF had been on the mend as time went on. Strongest changes took place in the first few days (Fig. 7).

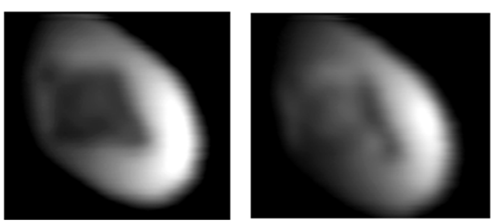

Figure 7. Intentionally damaged LaB6 on day 1 (l) and day 2 (r).

Emission contrast was falling off steadily, from initial 1.80X to 1.15X in 6 days (Fig.8).

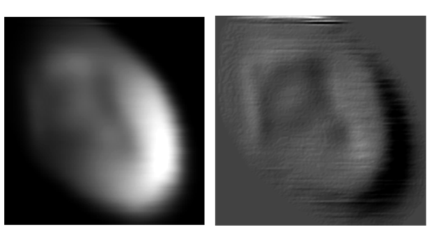

Figure 8. Intentionally damaged LaB6 on day 6.

At the end of this run, emission contrast fell to 1.10X, Fig. 9:

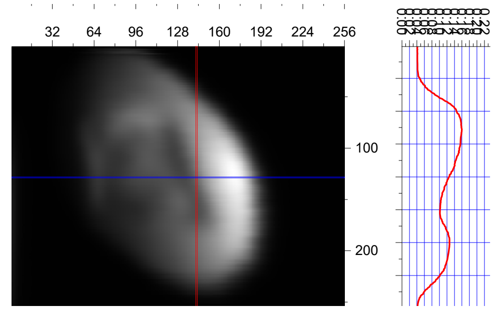

Figure 9. Intentionally damaged LaB6 emission contrast on day 15.

Meanwhile, WF kept improving along, reaching plateau in 11 days (Fig.10). Plateau WF value of 2.605 eV is typical for this type of LaB6 cathode.

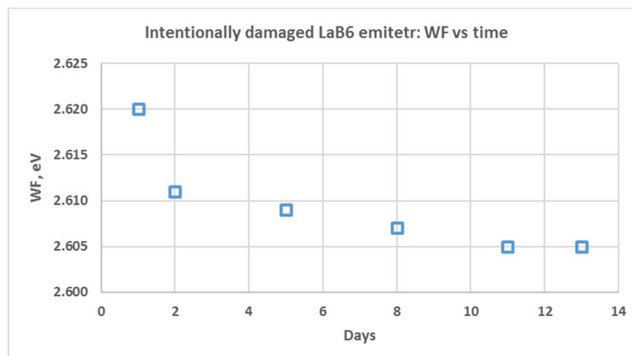

Figure 10. Intentionally damaged LaB6 cathode WF changes with time.

LaB6 surface self-healing: conclusion

Even severely damaged LaB6 (100) emitting surface may self-heal after several days of running at ~1800K in "dry" vacuum.

References

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2. V. Katsap, in Proceedings of IVEC 2017, paper 5.3