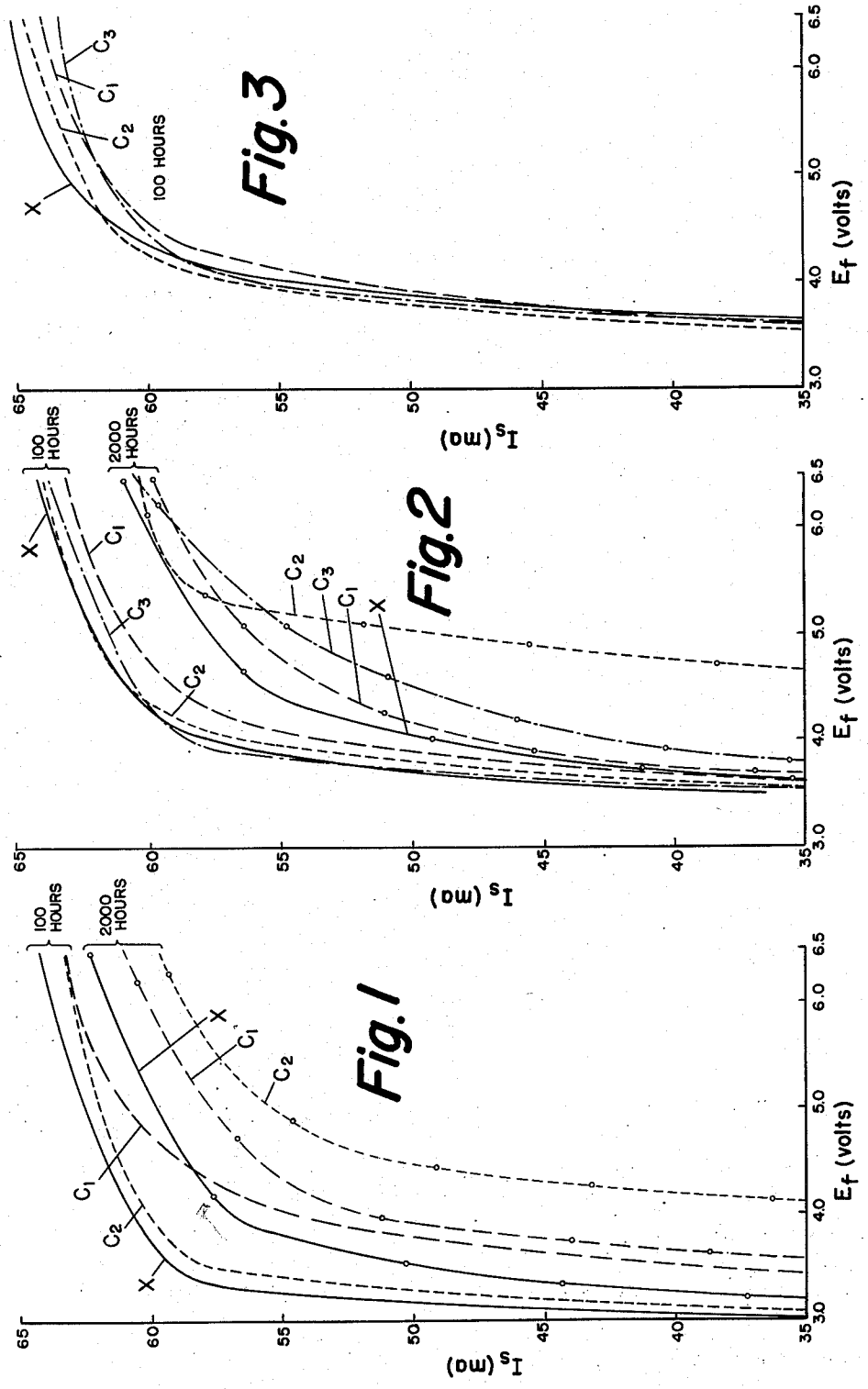
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Fig. 4

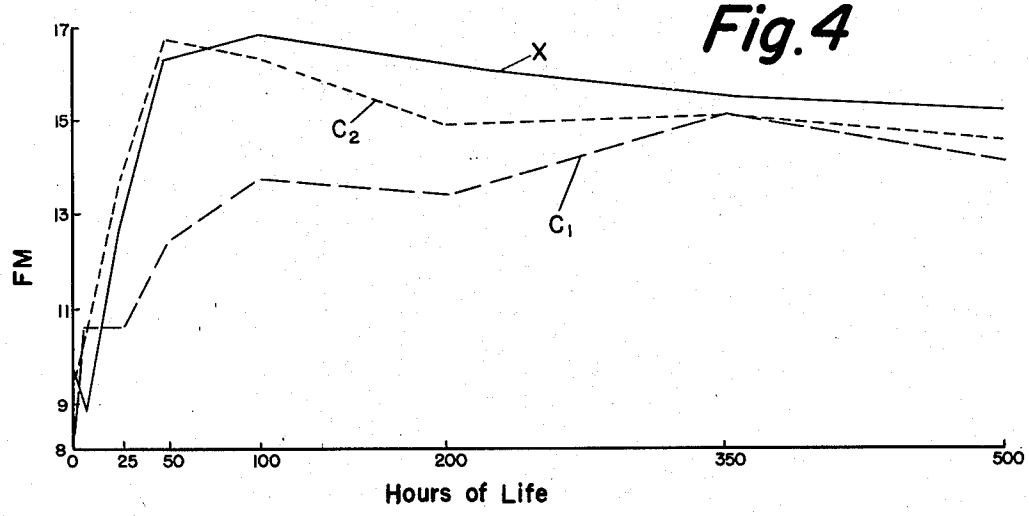


Fig. 5

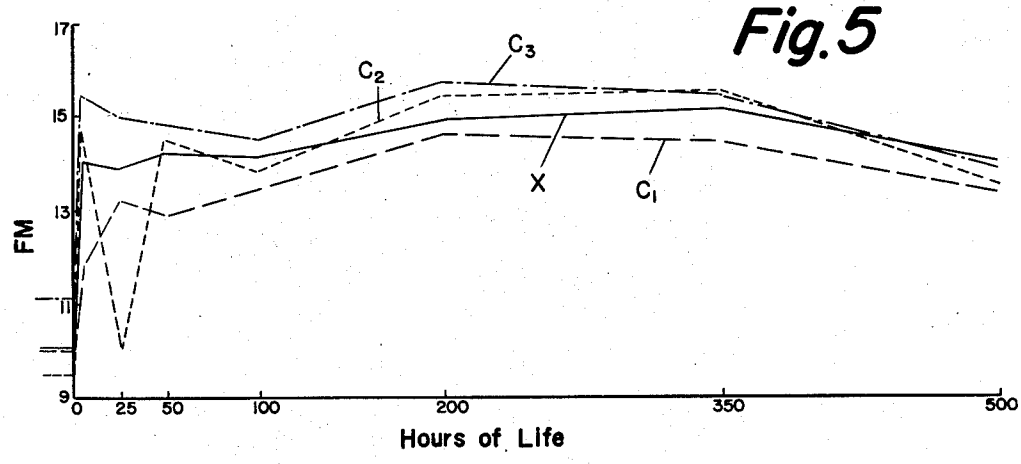
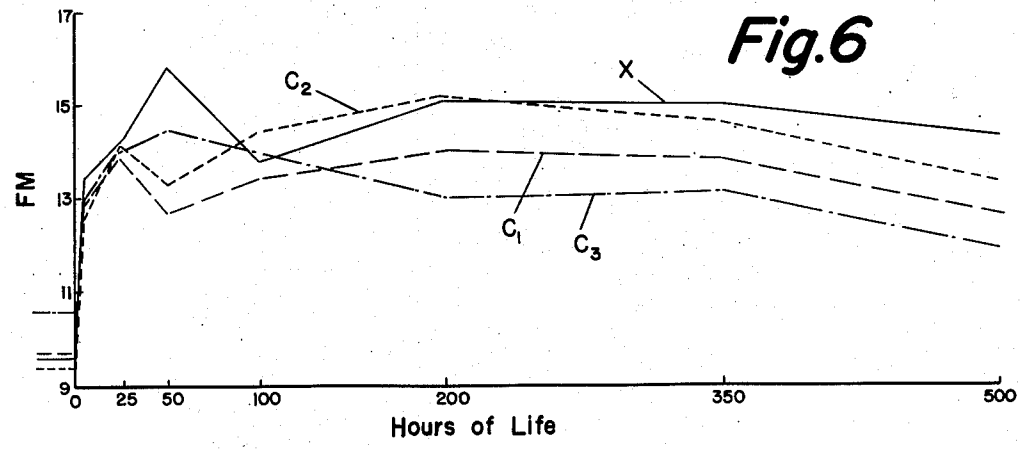


Fig. 6



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Fig. 7

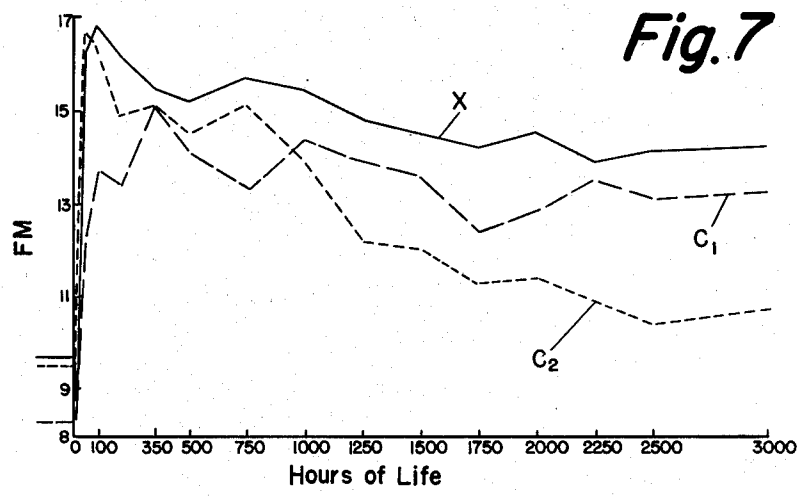


Fig. 8

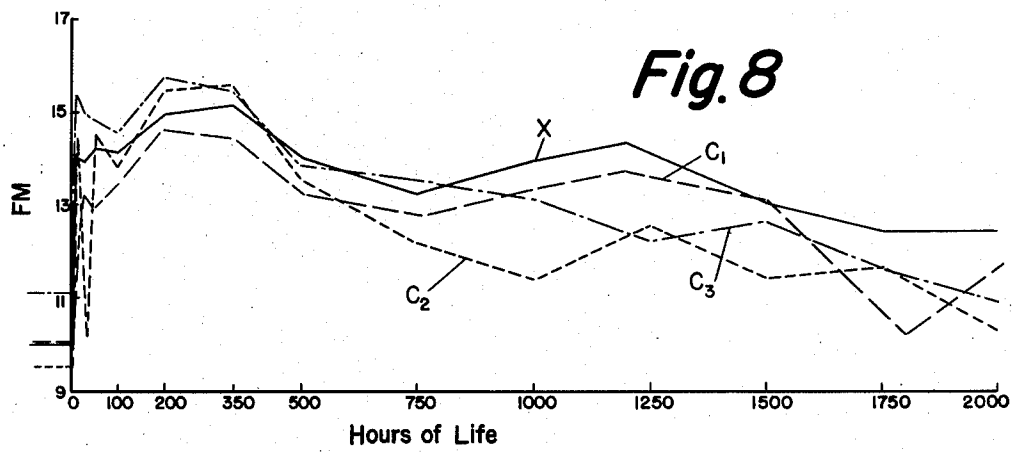
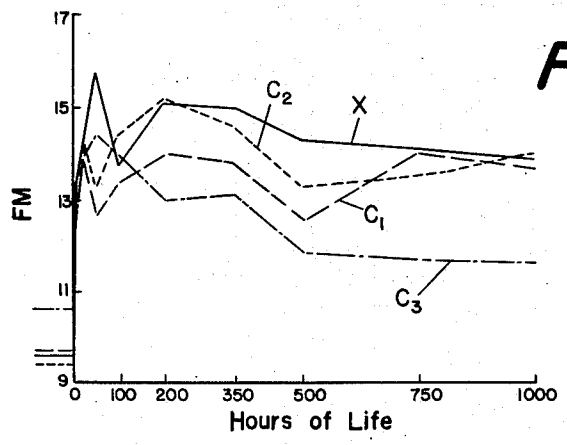


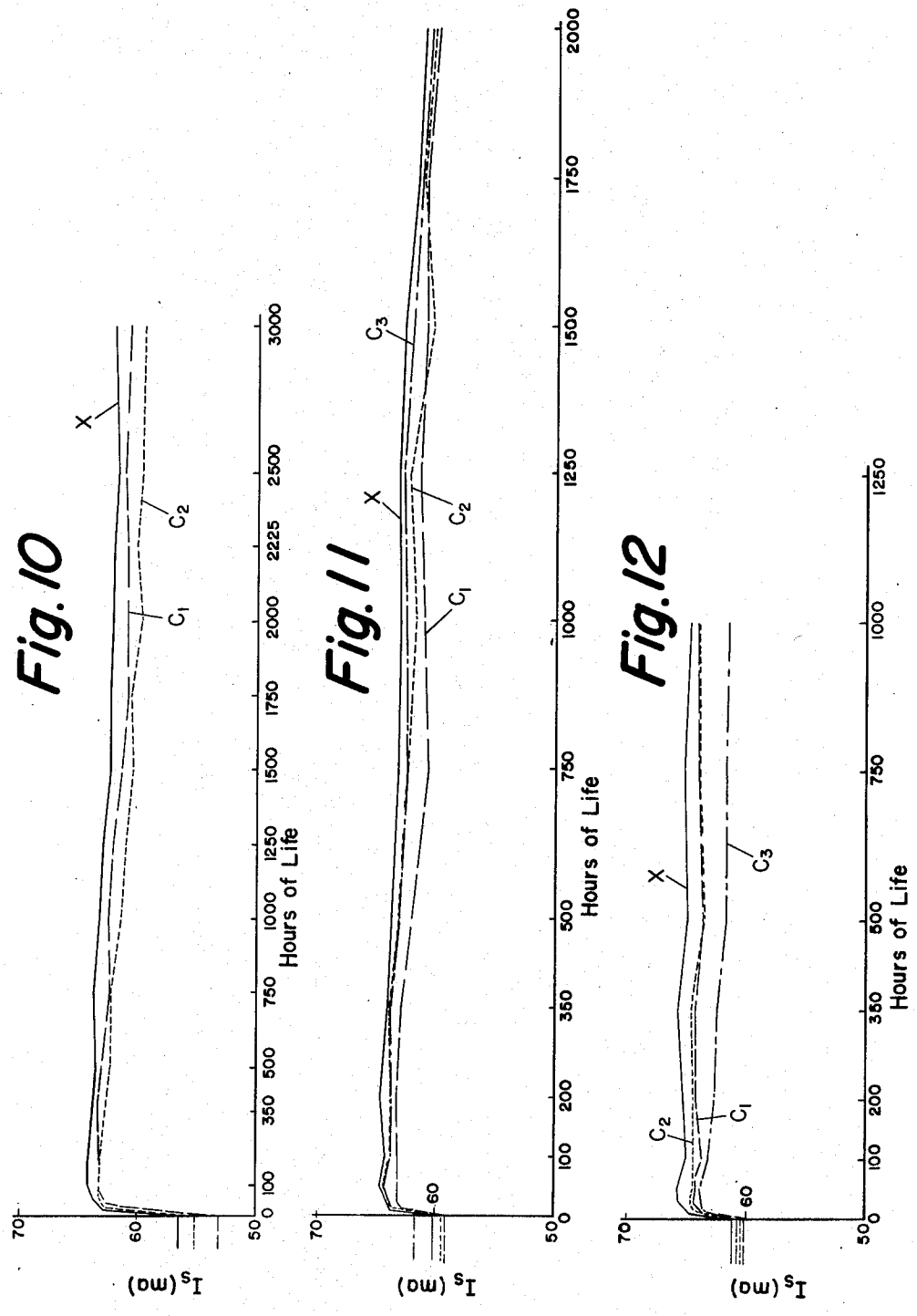
Fig. 9



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Fig. 13

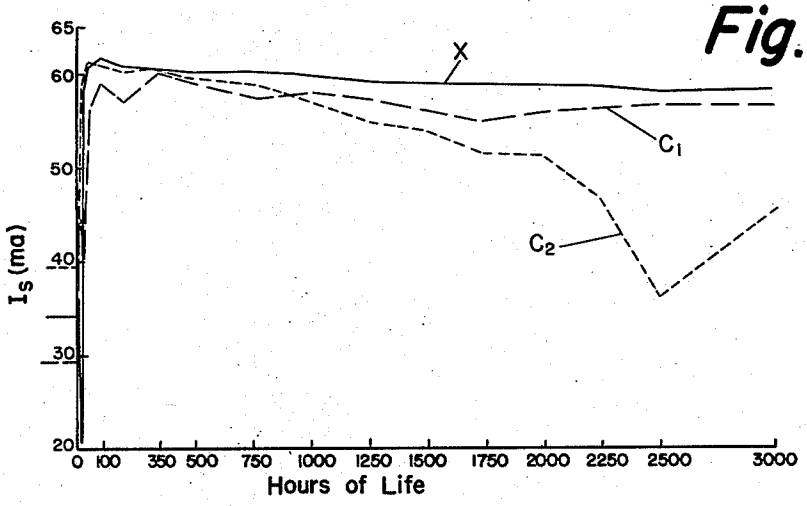


Fig. 14

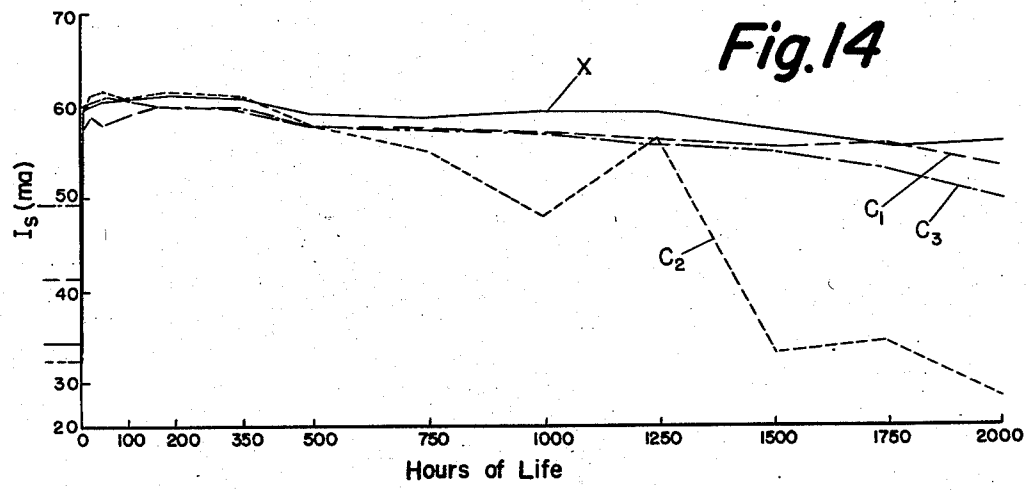
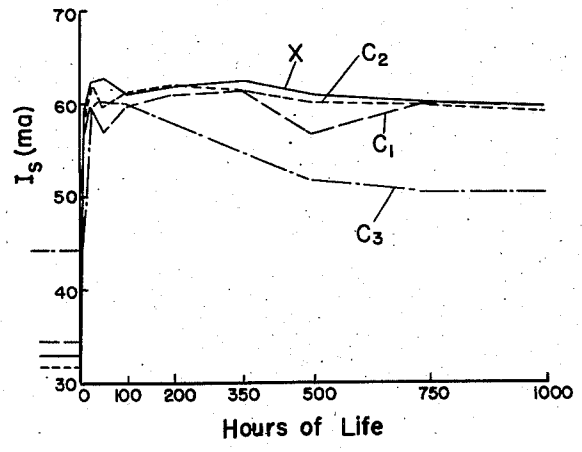


Fig. 15



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Fig. 16

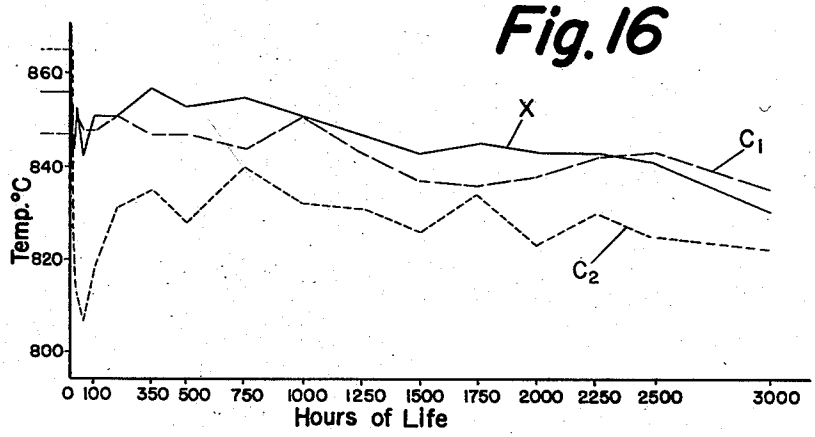


Fig. 17

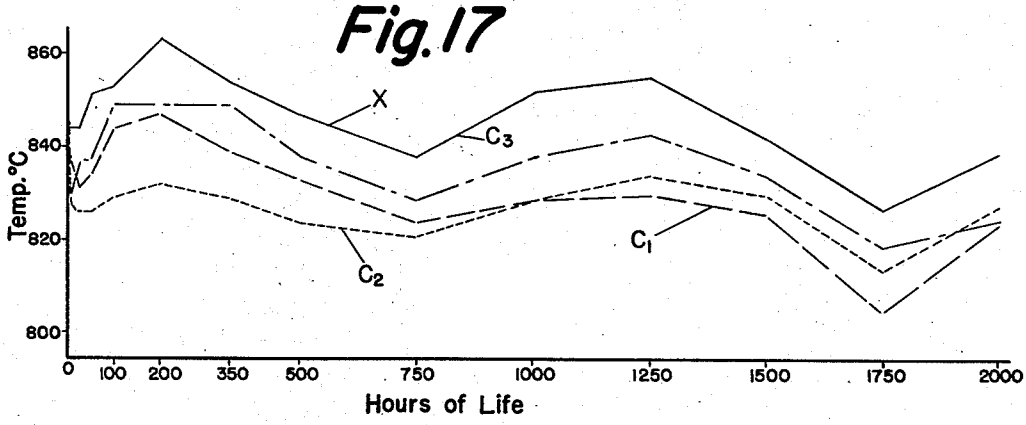
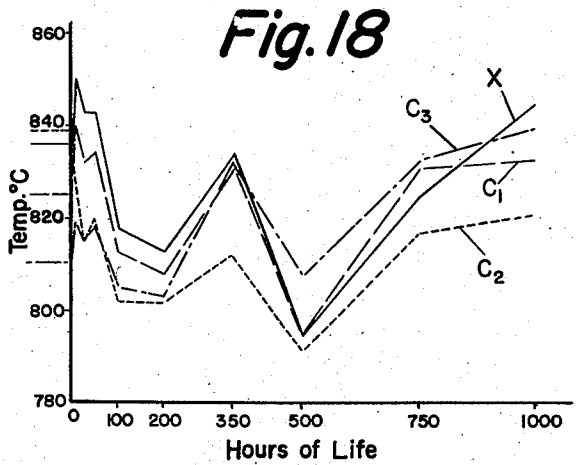


Fig. 18



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Fig. 19

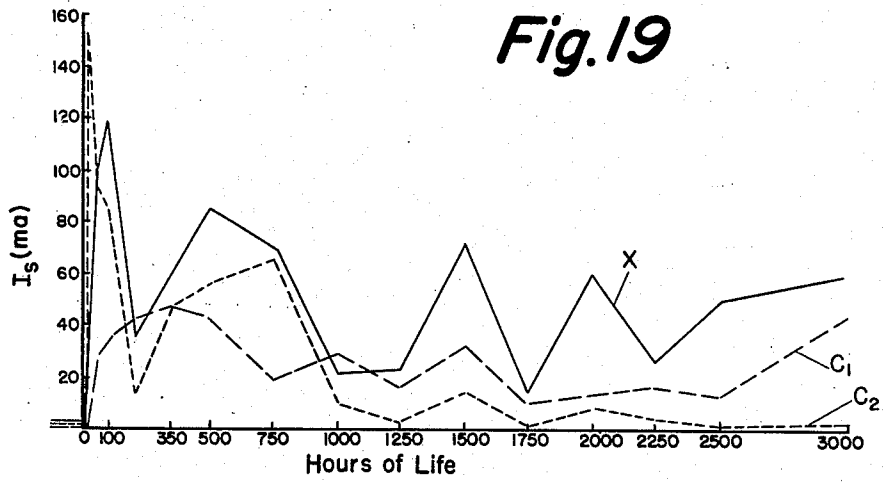


Fig. 20

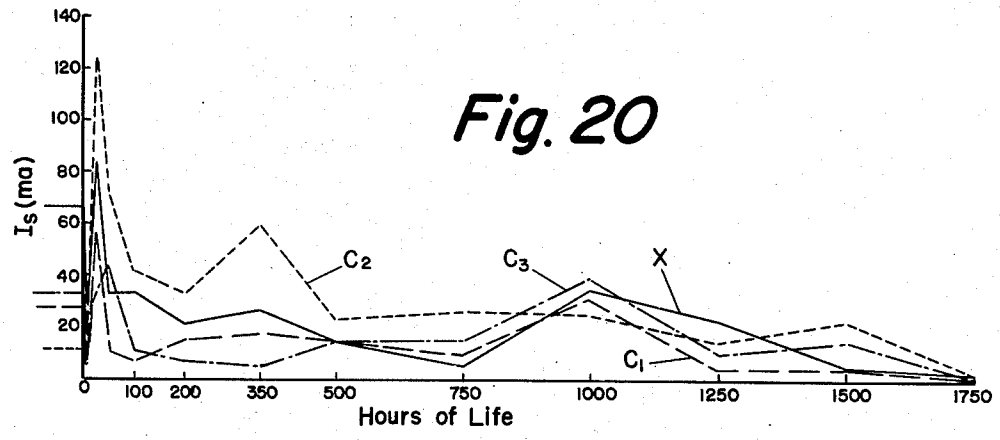
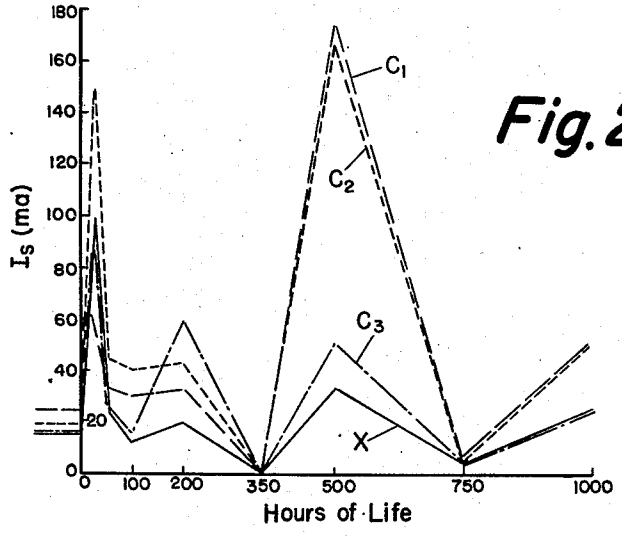


Fig. 21



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Fig. 22

Fig. 23

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ALLOYS FOR INDIRECTLY-HEATED CATHODES

Ardrey M. Bounds, Laverock, Pa., assignor to Superior Tube Company, Norristown, Pa., a corporation of Pennsylvania

Application November 15, 1955, Serial No. 546,963

18 Claims. (Cl. 75—170)

This invention relates to cathodes for electron tubes, and particularly relates to cathodes of the indirectly-heated type as distinguished from those of the directly-heated or filamentary type.

This application is in part a continuation of my co-pending application Serial No. 259,505, filed December 1, 1951, now abandoned.

The present invention is in the nature of an improvement upon that disclosed in my Patent 2,566,115. As set forth therein, the inclusion in the base nickel cathode alloy of a small percentage of aluminum within specified narrow limits is effective to shorten the initial activation period of the cathode, to increase the electron emission from the cathode at the same or lower operating temperature, to increase the effective cathode life, and to insure permanency and negligible electrical resistance of the mechanical bond between the cathode base element and its oxide coating of alkaline earth metals.

As originally disclosed in my aforesaid application Serial No. 259,505, all of these desirable cathode characteristics are retained, with enhancement of some of them, and in addition there is obtained greatly increased ability of the heated cathode to resist deformation under conditions of severe mechanical shock by inclusion in the aluminum-nickel alloy of tungsten within hereinafter specified narrow percentage limits.

Further and more specifically, the aluminum-tungsten-nickel alloys embraced by the present invention as suited for attainment, in indirectly-heated cathodes, of both greatly enhanced strength at high temperatures and high emission characteristics contain from about 0.5% to 5% tungsten and from about 0.01% to 0.25% aluminum. For obtaining the highest mechanical strength consistent with workability of the cathode alloy stock and for concurrence of superior emission characteristics, the optimum percentage of tungsten is about 4%. For obtaining the best emission characteristics concurrently with superior mechanical strength, the optimum percentage of tungsten is about 2%. In both cases, the preferred narrow range of aluminum is from about 0.05% to 0.1%.

In the following more detailed disclosure of the invention, reference is made to the accompanying Figures 1 to 23 of the drawings in which Figs. 1 to 21 show test curves, below specifically identified, of four cathode alloys, one of which is a tungsten-aluminum-nickel alloy embraced by the invention: More particularly;

Figs. 1 to 3 show curves of emission current vs. cathode-heater voltage;

Figs. 4 to 9 show curves of emission figure of merit vs. cathode life;

Figs. 10 to 12 show curves of emission at normal heater voltage vs. life;

Figs. 13 to 15 show curves of emission at subnormal heater voltage vs. life;

Figs. 16 to 18 show curves of cathode-coating temperature vs. life;

Figs. 19 to 21 show curves of low field emission vs. life;

Fig. 22 shows the curves of emission figure of merit vs. cathode life for five additional alloys within narrow preferred limits of tungsten and aluminum; and

Fig. 23 shows curves of emission figure of merit vs. cathode life for aluminum-tungsten-nickel alloys with excessive aluminum.

In general, indirectly-heated cathodes consist of a nickel alloy base element such as a sleeve or cup, having thereon a thin coating of alkaline earth metals such as barium, strontium and the like. After assembly of the cathode and other electrodes within an envelope to form an electronic tube, the cathode is activated by temporarily heating it to substantially above its normal operating temperature. During activation there are reactions between the base and coating materials which convert the coating to a combination of complex oxides of these materials. In subsequent use of the tube, the effective life of the cathode normally terminates when its electron emission is definitely subnormal at normal heater current.

Using coated cathodes having the usual prior nickel alloy sleeves, the effective life of high-voltage rectifier tubes in particular has often abruptly terminated far short of normal life expectancy because of eruptive flaking or peeling of the cathode coating. Also, the operation of amplifier, mixer and oscillator tubes has been adversely affected by formation of a high impedance interface between the cathode sleeve, or equivalent, and its coating. The electrical impedance of such interface further increases with age of the tube with corresponding greater impairment of tube performance. The resistive component of the interface impedance is damaging, particularly under cut-off operation, at ordinary frequencies: the capacitive component of the interface impedance is particularly damaging at high frequencies even when the tube is not operating under cut-off condition.

Such prior cathodes were also unduly sensitive to reduced heater voltage so that under conditions of fluctuating line voltage or of low available voltage, as often encountered in field operations, the operation of the tubes was unsatisfactory. Furthermore, when such tubes were subjected to severe mechanical shock, due for example to the extremely high accelerations encountered in missile equipment, they were often rendered inoperative before performing their intended purpose because of buckling or deformation of the cathode with resultant internal short-circuit or significant change of interelectrode spacing, resulting in substantial changes in electrical characteristics. Bowing also occurred when during the activating period, cathodes of usual nickel alloy sleeves were heated to high temperature in efforts to shorten the activation period.

As shown by test curves later discussed, these shortcomings and disadvantages are overcome by using indirectly-heated cathodes made of a nickel alloy including aluminum (Al) and tungsten (W) within narrow limits of specified low percentages. In tabular form, the broadest range of percentage composition suitable for attainment of these electrical and mechanical properties is shown in the following table.

TABLE I

Base:	
Ni	94–99.5%.
Co	1% max.
Major activating:	
Al	0.01%–0.25%.
W	0.5–5%.
Minor activating:	
Mg	0.15% max.
Si	0.25% max.

Residual:

Cu	0.2% max.
Fe	0.2% max.
C	0.2% max.
Mn	0.2% max.
Ti	0.05% max.
S	0.01% max.

All of the beneficial effects of aluminum and tungsten within the ranges above specified obtain if the cathode alloy also includes as minor activating agents a small percentage of magnesium (Mg) or silicon (Si), or both. A range of 0.01% to 0.25% is suitable for silicon: a range of 0.01% to 0.15% is suitable for magnesium: the combined percentage range of both is 0.03% to 0.4% within the above specified maximum limits of 0.15% magnesium, 0.25% silicon. Impurities or residuals, such as copper, iron, carbon, sulphur and titanium, should not be present in percentages higher than specified in Table I above. Cobalt, usually present with nickel, appears to have no particular effect upon the emissive, hot strength and life properties of the cathode unless present in quantity greater than 1%.

Although tungsten itself was previously considered a poor cathode activating material, in combination with aluminum within the range specified, it has been found by me to have a beneficial effect upon emission. This has been explained by the fact that Ba_3WO_6, Ba_2TiO_4 and Ba_2SiO_4 all react with aluminum to produce $BaAl_2O_4$ and to free barium, in accordance with reactions of the type

(1) $\frac{2}{3}Ba_3WO_6(s)+2Al(l)=BaAl_2O_4(s)+\frac{2}{3}W(s)+Ba(g)$

and

(2) $Ba_2TiO_4(s)+2Al(l)=BaAl_2O_4(s)+Ti(s)+Ba(g)$

The hot strength of indirectly-heated cathodes improves progressively with addition of tungsten but for percentages appreciably in excess of about 5%, the higher cost is without compensatory improvement in emission characteristics. Also for such higher percentages of tungsten, there arise difficulties in working the alloy stock to form the metal sleeves, or equivalent cathode elements, by punching, stamping or like metal-working steps. The problems encountered in workability of the cathode stock are very severe since, for example, seamless cathodes are made with external diameters as small as .010 inch with a wall thickness of 0.0015 inch: lockseam, lap-seam and buttseam cathodes are made as small as 0.020 outer diameter and 0.002 wall thickness.

For highest hot-strength consistent with workability and enhanced emission properties, the optimum percentage of tungsten in the tungsten-aluminum-nickel alloy is about 4%: for this percentage, electronic tubes subjected to shock levels of 1000 g do not suffer cathode bowing. For highest emissive properties and substantially enhanced hot-strength, the optimum percentage of tungsten in the ternary alloy is about 2%.

The optimum percentage of aluminum in the ternary alloy is from about 0.05% to 0.1%. With less aluminum, its beneficial effects are insubstantial: percentages of aluminum much above 0.2% are unsatisfactory in one or more respects. Specifically, for upwards of 0.25% aluminum, although the cathode sleeves activate rapidly and initially have high emission, their life is relatively short. Furthermore, for upwards of 0.25% aluminum, it is difficult to fabricate lockseam cathodes and seamless cathodes of small diameter because edge-cracking and flaking of the metal stock precludes use of the cathodes in electron tubes.

As a specific example of an alloy within the limits of Table I, reference is made to alloy X of Table II below:

TABLE II

	X	C_1	C_2 (Inco 220)	C_3
Al	.058	0	.008	.105
Co	.995	0	.705	.172
Cu	.034	.011	.020	.014
Fe	.191	.019	.061	.015
Mg	.019	.043	.032	.054
Mn	.090	.002	.107	.002
Si	.025	.035	.023	.007
Ti	.005	.003	.030	.004
W	1.85	4.15	0	0
Ni	Essentially Remainder			

The superior characteristics of alloy X for indirectly-heated cathodes as compared with the characteristics of tungsten-nickel, aluminum-nickel and "normal" cathode alloys C_1 to C_3 of Table II and as evaluated by use of the ASTM standard diode structure are shown by

(1) Figs. 1–3: curves of emission current vs. heater voltage at initial and end-of-life periods;
(2) Figs. 4–9: emission figure of merit vs. life;
(3) Figs. 10–15: emission at specified heater voltages during life;
(4) Figs. 16–18: cathode coating temperature vs. life;
(5) Figs. 19–21: low field emission during life;
(6) Table III; percent ΔI_s
(7) Table IV: dome deposit formation.

These seven evaluation factors are discussed below under similarly numbered paragraphs.

(1) Figs. 1 to 3 show the relative merit of the alloys of Table II in regard to maximum emission and in sustaining emission at reduced or subnormal cathode temperature. The emission current was measured with 40 volts (D. C.) applied to the anode and with from 2.5 to 6 volts (in 0.5 volt increments) applied to the cathode heater. At the initial period of life (100 hours), the emission of the tungsten-aluminum-nickel (X) cathode was higher than the others especially at heater voltages above 4.5. At the 2,000-hour life period, the tungsten-aluminum-nickel (X) cathode maintained higher emission levels throughout the entire range of heater voltages.

(2) The rate of activation is determined by the level and time for the D. C. emission figures of merit (I_sFM) to reach a maximum value. D. C. life is evaluated by the variation of the figure of merit throughout life; the activation and early life (500 hours) of the alloys of Table II are shown in Figs. 4 to 6, and their complete life curves are shown in Figs. 7 to 9. In one life test (Fig. 4), the tungsten-aluminum-nickel (X) cathode activated to a higher degree than the tungsten-nickel cathode as did the normal cathode of alloy C_2. In the two other tests (Figs. 5–6), the time for activation was about the same for all alloys of Table II. In one of these tests (Fig. 6), the tungsten-aluminum-nickel (X) attained the highest level: in the other tests (Fig. 5), the tungsten-aluminum-nickel (X) was again higher than tungsten-nickel but lower than aluminum-nickel. In all complete life tests (Figs. 7 to 9), the tungsten-aluminum nickel (X) cathode had, after stabilization, the highest and most uniform level of figure of merit.

(3) As shown in Figs. 10 to 12, all alloys of Table II reach their maximum emission levels at approximately the same time for normal heater voltage (6.5 volts). However, the tungsten-aluminum-nickel (X) cathode attained the highest level in all tests and maintained the higher level throughout life. The relation between the other alloys of Table II differed for the different tests. As shown by Figs. 13 to 15, the tungsten-aluminum-nickel (X) cathode also had the highest and most stable level of emission throughout life at subnormal heater voltage (4.5 volts). The relation between the other alloys of Table II differed for different tests: specifically, in two of them (Figs. 13, 14), the emission of the "nor-

mal" cathode dropped off sharply during life, and in another (Fig. 15), the emission of the aluminum-nickel (C_3) cathode decreased with life.

(4) Figs. 16 to 18 show the variation with life of the surface temperature of the various coated cathodes of Table II, as measured by an optical pyrometer sighted through an aperture in the associated anode. For the same heater voltages, the tungsten-aluminum-nickel (X) cathodes had temperatures approximately 10° C. higher than the temperature of the next hottest cathode; that is to say, the tungsten-aluminum-nickel alloy shows lower thermal losses than the other alloys. Thus at the standardized reduced voltage test point of 4.5 heater voltage, the alloy (X) cathode still operates space-charge limited, whereas the other alloys operate temperature-limited.

(5) In two of the tests for low field emission, the heater and anode voltages were 1.75 and 4 volts: in the third tests, the heater voltage was 2 volts and the anode voltage was 5 volts. This change in voltages was in effort to reduce emission variations. The emission under the voltage conditions specified is temperature-limited and therefore sensitive to any change in cathode temperature. The variation in emission current noted throughout these tests is believed due to cathode temperature changes occasioned by variations in physical contact of the heater, cathode and interelectrode micas. Despite these uncontrollable variations, the low field emission level for the tungsten-aluminum-nickel (X) cathode was definitely better than the others for one of these tests (Fig. 19).

(6) Percent ΔI_s is the change in emission that occurs when the heater voltage is reduced from 6.5 volts to 5.5 volts. It is a measure of the ability of the cathode to maintain uniform emission current corresponding with changes of heater voltage of magnitude commonly experienced with changes in load of power supply lines. In the test of Table III below, the tungsten-aluminum-nickel (X) cathode is shown to have the least change in emission by end of life and therefore is more stable than the other cathodes of Table II; i. e., the cathode having the lowest percent ΔI_s is the superior cathode.

TABLE III

Alloy	Percent ΔI_s (at 100 hours)	Percent ΔI_s (at 2,000 hours)	Percent ΔI_s (at 3,000 hours)
X of Table II	1.68	2.70	3.11
C_1 of Table II	1.90	3.53	3.72
C_2 of Table II	1.36	4.15	5.73

(7) As shown by Table IV below, the sublimation rate of tungsten-aluminum-nickel (X) cathodes is extremely low despite the fact they are characterized by the highest operating temperature. It was the last in each test to show any deposit of sublimed metal, and after 3,000 hours of operation there was only a trace of dome deposit formation whereas by that time the diodes using the other cathodes of Table II had heavy sublimed metal deposits. These tests show that tubes using tungsten-aluminum-nickel cathodes will have longer life, so far as interelectrode leakage is concerned, than similar tubes using cathodes of the other alloys of Table II.

TABLE IV

Rate of dome deposit formation

TEST 1

	X	C_2	C_1
Hours for deposit to form	100	50	0.
Diameter and density at end of life (3,000 hours).	trace	4 mm. heavy.	6 mm. heavy.

TEST 2

	X	C_2	C_1	C_3
Hours for deposit to form	1,750	1,000	0	0.
Diameter and density at end of life (3,000 hours).	very faint trace.	faint trace.	7 mm. heavy.	6 mm. heavy.

Knowing from experience that the effect of additives to the base nickel alloy upon cathode characteristics is not predictable and that alloys suitable for filamentary cathodes have been, in practically all cases, found unsuitable for commercially useful indirectly-heated cathodes, tests of the foregoing character for determining such effect have been made on a large number of tungsten-aluminum-nickel alloys. The alloys tested included alloys within a high-tungsten, high-aluminum range of 4 to 5% tungsten and 0.15 to 0.25% aluminum; the medium-tungsten, medium-aluminum range of 1.75% to 2.5% tungsten and 0.07 to 0.15% aluminum; and the low-tungsten, low-aluminum range of less than 1% tungsten and less than 0.07% aluminum. Alloys X_1 to X_5 of Table V and alloy X of Table II above are exemplary of those tungsten-aluminum-nickel alloys which have been found to define, within the limits of Table I, still narrower limits of aluminum and tungsten which are best suited for indirectly-heated cathodes considering all of the many factors involved. Of these, alloy X_4 of Table V below has been selected for extensive commercial production.

TABLE V

Alloy	Base Alloy		Major Activating		Minor Activating		Residual				
	Ni	Co	Al	W	Mg	Si	Cu	Fe	C	Mn	Ti
X_1	[1]	.071	.050	2.1	.015	.008	.010	.050	.08	.086	<.002
X_2	[1]	.12	.051	.73	.037	.003	.015	.021	.08	.082	<.002
X_3	[1]	.082	.08	1.94	.034	.016	.012	.019	.05	.081	.005
X_4	[1]	.53	.076	2.47	.026	.006	.011	.030	.03	.065	.004
X_5	[1]	.125	.170	4.83	.036	.005	.012	.022	.04	.078	<.002

[1] Remainder.

As shown by the curves of Fig. 22 and as indicated in Table VI, all of the tungsten-aluminum-nickel alloys of Table V activate rapidly and retain their characteristic of high emission throughout a long life.

TABLE VI

Characteristics	X_1	X_2	X_3	X_4	X_5
First sign of dome deposit	none	25 hr	350 hr	none	25 hr.
Type and diameter of deposit	none (1,000 hr.)	heavy, 5 mm	trace, 1 mm	none (750 hr.)	heavy, 2 mm.
Activation Rate (time to reach stability):					
I_s at 6.5 v. (E_f)	25 hr	25 hr	25 hr	5 hr	25 hr.
I_s FM	100 hr	50 hr	100 hr	50 hr	25 hr.
Max emission level and time:					
I_s at 6.5 v. (E_f)	64.5 Ma. (100 hr.).	63.6 Ma. (50 hr.).	64.1 Ma. (100 Hr.)	64.1 Ma. (200 hr.).	63.4 Ma. (100 hr.).
I_s at 4.5 v. (E_f)	61.8 Ma. (100 hr.).	60.6 Ma. (50 hr.).	61.7 Ma. (100 hr.).	60.9 Ma. (25 hr.).	60.8 Ma. (50 hr.)
I_s FM	15.4 (100 hr.)	16.1 (50 hr.)	15.8 (100 hr.)	16.3 (350 hr.)	15.8 (25 hr.).
D. C. life emission:					
I_s at 6.5 v. (E_f)	62.6 Ma. (1,000 hr.).	62.3 Ma. (1,000 hr.).	62.5 Ma. (1,000 hr.).	62.7 Ma. (750 hr.).	63 Ma. (1,000 hr.).
I_s at 4.5 v. (E_f)	59.6 Ma. (1,000 hr.).	58.1 Ma. (1,000 hr.).	59.2 Ma. (1,000 hr.).	57.2 Ma. (750 hr.).	56.2 Ma. (1,000 hr.).
I_s FM	13.8	14.5	14.2	15.7	13.8.
Cathode Coating Temperature: 7.5 v. (E_f)	816° C. (1,000 hr.).	834° C. (1,000 hr.).	810° C. (1,000 hr.).	854° C. (750 hr.)	767° C. (1,000 hr.).
Heater-Cathode Leakage:					
6.3 v. (E_f)	0	2.0μa	0.1μa	0	0.
100 v. (E_{hk})					
Diode Analysis:					
Interface Color—					
(before life)	A	A—	A	A+	A.
(after life)	D—	A—	A—	A—	A—.
Coating Texture (after life)	M—	M—	M—	M—	M.
Coating Hardness (after life)	M	M	M—	S	S+.
Coating adherence	Good	Good	Good	Good	Good.
Plate-Cathode Spacing:					
(before life)	.0403	.0406	.0406	.0409	.0406.
(after life)	.0407	.0410	.0401	(*)	.0404.
Apparent Density of Coating: (mg. per cu. mm.).	.77	.83	.77	.798	.78.
Unit Weight of Coating (mg. per sq. mm.).	7.86	7.86	7.86	7.76	7.67.

*Coating came off on exposure to air.

Also as shown in Table VI, all of alloys X_1 to X_5 have high and stable emission throughout life at subnormal heater voltage (4.5 volts) which well adapts indirectly-heated cathodes of these alloys for satisfactory operation in the field or under other conditions of fluctuating or low values of available heater voltage.

Also as shown in Table VI, with cathode sleeves of these alloys, the oxide coating remained bonded to the sleeve throughout the cathode life and with insignificant change of the spacing to the associated anode.

In general, indirectly-heated cathodes made of alloys X_1 to X_5 exhibit superior emission characteristics and enhanced strength of alloy X previously discussed. By way of specific example, alloy X_4 has a hot-deflection strength suitable to preclude deformation of more than 1 mil at a pressure of 3750 lb./sq. inch at temperatures of about 900° C. This alloy and others within the preferred narrow limits of aluminum and tungsten have high strength and low sublimation rate even at above normal operating temperatures. As above pointed out, these alloys have high, stable emission even at subnormal heater voltage (subnormal operating temperature). Thus cathodes of these alloys exhibit under widely different heater voltages substantially the same operating characteristics throughout a protracted life.

By way of contrast and as illustrative of the inferior emissive characteristics resulting when the aluminum content in the ternary alloy is increased to about 0.5%, reference is made to Table VII below and to Fig. 23.

TABLE VII

Alloy	Base Alloy		Major Activating		Minor Activating		Residual				
	Ni	Co	Al	W	Mg	Si	Cu	Fe	C	Mn	Ti
C_5	(1)	.105	.515	.866	.02	.023	.01	.107	.094	.108	.008
C_6	(1)	.100	.515	.892	.012	.007	.011	.028	.011	.018	.002

1 Remainder.

As shown by the curves of Fig. 23, although alloys C_5 and C_6 afford rapid activation of the cathode sleeves, the emission falls quite rapidly from the maximum attained in the first 50 hours of life. After less than 200 hours of life, the emission of indirectly-heated cathodes made of these alloys is markedly less (compare with Figs. 7 to 9 and 22) than the emission maintained by the X to X_5 alloys throughout a much longer operating life.

It is also to be noted from Table VIII that for cathode sleeves made of alloys C_5 and C_6, there is poor adherence of the oxide coating to the sleeve and strong probability of early termination of cathode life by flaking or peeling of the coating. It is also to be noted that for these alloys C_5 and C_6 after the initial short period of high emission, the emission is very substantially affected by change in heater voltage.

TABLE VIII

Characteristics	C_5	C_6
First sign of dome deposit	200 hr.	none.
Type and diameter of deposit	heavy, 2 mm.	none.
Activation Rate:		
I_s at 6.5 v. (E_f)	5 hr.	5 hr.
I_s FM	50 hr.	50 hr.
Max emission Level and time:		
I_s at 6.5 v. (E_f)	63.6 Ma. (100 hr.)	63.3 Ma. (50 hr.).
I_s at 4.5 v. (E_f)	60.4 Ma. (50 hr.)	60.7 Ma. (50 hr.).
I_s FM	16 (50 hr.)	15.9 (50 hr.).
D. C. Life Emission:		
I_s at 6.5 v. (E_f)	57.2 Ma. (1,000 hr.)	58.6 Ma. (1,000 hr.).
I_s at 4.5 v. (E_f)	37.6 (1,000 hr.)	38.4 Ma. (1,000 hr.).
I_s FM	8.8	8.8.
Cathode Coating Temperature: 7.5 v. (E_f).	825° C.	806° C.
Heater-Cathode Leakage:		
6.3 v. (E_f)	2 μa.	0.2 μa.
100 v. (E_{hk})		
Visual Analysis of Diode:		
Interface Color—		
(before life)	A	L+.
(after life)	L−	L.
Coating Texture	S	S−.
Coating Hardness	Poor	Poor.
Coating Adherence		
Plate Cathode Spacing—		
(before life)	.0411	.0403.
(after life)	coating peeled off.	coating peeled off.
Apparent density of Coating	.79	.79.
Unit Weight of Coating	7.72	7.72.

From extensive investigation of aluminum-tungsten-nickel alloys, in part reproduced in the drawings and tables above, it has been determined that the preferred narrow limits of tungsten and aluminum for the sleeves or equivalent base structures of indirectly-heated cathodes are those defined by Table IX below.

TABLE IX

Base alloy:	
Ni	Remainder.
Co	1% max.
Major activating agents:	
Al	.05 to .10.
W	2.0 to 2.5.
Minor activating agents:	
Mg	0.01 to 0.06.
Si	.03 max.
Residual:	
Cu	.05 max.
Fe	.10 max.
C	0.3 to 0.10.
Mn	.05 max.
Ti	.01 max.
S	.005 max.

Within the narrow limits of tungsten and aluminum of Table IX above, such cathodes exhibit optimum manufacturing, activating, life and operating characteristics taking into account all of the many factors above discussed.

What is claimed is:

1. A metallic cathode element of the indirectly-heated oxide-coated type characterized by electrical properties of rapid activation, enhanced emission, increased life and permanent low electrical impedance of the bond to the cathode coating and by the mechanical properties of ease of formation by metal-working steps and resistance to deformation when subjected to severe shock, said element being of an alloy containing nickel above about 94%, tungsten in the range of 0.5% to 5%, aluminum in the range of 0.01% to 0.25%, and not significantly in excess of 1% cobalt, 0.15% magnesium, 0.25% silicon, 0.2% copper, 0.2% iron, 0.2% carbon, 0.2% manganese, 0.05% titanium, and 0.01% sulphur.

2. A cathode element as in claim 1 in which the aluminum-tungsten-nickel alloy includes magnesium within the range of from 0.01% to 0.15% as a minor activating agent.

3. A cathode element as in claim 1 in which the aluminum-tungsten-nickel alloy includes silicon within the range of from 0.01% to 0.25% as a minor activating agent.

4. A cathode element as in claim 1 in which the aluminum-tungsten-nickel alloy includes the minor activating agents magnesium and silicon within the combined percentage range of from 0.03% to 0.4% and within the maximum limits of 0.15% magnesium, 0.25% silicon.

5. An indirectly-heated cathode structure characterized by high hot strength and composed of a ternary alloy containing 0.5% to 5% tungsten, 0.01% to 0.25% aluminum and the remainder essentially nickel.

6. An indirectly-heated cathode structure characterized by high hot strength and good thermionic emission properties comprising a cathode base coated with electron-emissive material, said base being composed of a ternary alloy containing 0.5% to 5% tungsten, 0.01% to 0.25% aluminum and the remainder essentially nickel.

7. In an electron discharge device, an indirectly-heated hollow cathode structure coated with electron-emissive material, said structure being composed of a ternary alloy containing 0.5% to 5% tungsten, 0.01% to 0.25% aluminum and the remainder essentially nickel.

8. An indirectly-heated cathode structure characterized by high hot strength and good thermionic-emission properties comprising a cathode base element coated with electron-emissive material, said base being composed of a ternary nickel alloy containing as major activating agents 0.5% to 5% tungsten and 0.01% to 0.25% aluminum, and at least one of the minor activating agents magnesium and silicon within the combined percentage range of from 0.03% to 0.4% and within the maximum limits of 0.15% magnesium, 0.25% silicon.

9. An indirectly-heated cathode structure having the characteristics of rapid activation, high and stable emission over a substantial range of heater voltage, high strength and low sublimation at above normal operating temperatures and composed of a ternary nickel alloy containing aluminum 0.05% to 0.10%, tungsten 2% to 2.5%, and the remainder essentially nickel.

10. An indirectly heated cathode structure as in claim 9 in which the aluminum-tungsten-nickel alloy includes magnesium within the range of from 0.01% to 0.06% as a minor activating agent.

11. A metallic cathode element of the indirectly-heated oxide-coated type characterized by electrical properties of rapid activation, enhanced emission, increased life and permanent low electrical impedance of the bond to the cathode coating and by the mechanical properties of ease of formation by metal-working steps and resistance to deformation when subjected to severe shock, said element

being of an alloy containing nickel above about 94%, tungsten in the range of 0.5% to 5%, aluminum in the range of 0.01% to 0.2%, and not significantly in excess of 1% cobalt, 0.15% magnesium, 0.25% silicon, 0.2% copper, 0.2% iron, 0.2% carbon, 0.2% manganese, 0.05% titanium, and 0.01% sulphur.

12. A cathode element as in claim 11 in which the aluminum-tungsten-nickel alloy includes magnesium within the range of from 0.01% to 0.15% as a minor activating agent.

13. A cathode element as in claim 11 in which the aluminum-tungsten-nickel alloy includes silicon within the range of from 0.01% to 0.25% as a minor activating agent.

14. A cathode element as in claim 11 in which the aluminum-tungsten-nickel alloy includes the minor activating agents magnesium and silicon within the combined percentage range of from 0.03% to 0.04% and within the maximum limits of 0.15% magnesium, 0.25% silicon.

15. An indirectly-heated cathode structure characterized by high hot strength and composed of a ternary alloy containing 0.5% to 5% tungsten, 0.01% to 0.2% aluminum and the remainder essentially nickel.

16. An indirectly-heated cathode structure characterized by high hot strength and good thermionic emission properties comprising a cathode base coated with electron-emissive material, said base being composed of a

ternary alloy containing 0.5% to 5% tungsten, 0.01% to 0.2% aluminum and the remainder essentially nickel.

17. In an electron discharge device, an indirectly-heated hollow cathode structure coated with electron-emissive material, said structure being composed of a ternary alloy containing 0.5% to 5% tungsten, 0.01% to 0.2% aluminum and the remainder essentially nickel.

18. An indirectly-heated cathode structure characterized by high hot strength and good thermionic-emission properties comprising a cathode base element coated with electron-emissive material, said base being composed of a ternary nickel alloy containing as major activating agents 0.5% to 5% tungsten and 0.01% to 0.2% aluminum, and at least one of the minor activating agents magnesium and silicon within the combined percentage range of from 0.03% to 0.4% and within the maximum limits of 0.15% magnesium, 0.25% silicon.

References Cited in the file of this patent

UNITED STATES PATENTS

2,103,267	Mandell	Dec. 28, 1937
2,223,862	Widell	Dec. 3, 1940
2,323,173	Widell	June 29, 1943
2,566,115	Bounds	Aug. 28, 1951

FOREIGN PATENTS

111,841	Australia	Apr. 29, 1943