

Microstructure of Cast and Wrought Aluminum Alloys

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Aluminum and its Alloys

- Cast vs. Wrought
- Heat Treatable (PH) vs. Non-heat Treatable
- Non-heat Treatable – Strengthen by Cold Work
 - Strengthen by Alloying

Cast Aluminum Alloys

- Silicon is Major Alloying Element
 - Silicon Improves Fluidity
- Near-Eutectic Compositions - for Die Casting
- Refine Eutectic by Adding Sodium (shifts eutectic to about 14% Si)
- Add Copper to Permit Heat Treatment

Intermetallic Phase

Compounds or intermediate solid solutions containing two or more metals, that usually have characteristic properties and crystal structures different from those of the pure metals or the terminal solid solutions.

Age Hardening

The process of increasing the strength of a metallic material by a relatively low-temperature heat treatment that causes precipitation from solid solution of a second structural component or phase that is usually sub-microscopic in size.

Solution Anneal

A treatment in which an alloy is heated to a suitable temperature for a sufficient length of time to allow a desired constituent to enter into solid solution, followed by rapid cooling to hold that constituent in solution. The alloy is then in a super-saturated, unstable state, and may exhibit age hardening.

Intermetallics in Al

Occur because Al is highly electronegative and trivalent. The stability and narrowness of their composition is determined by size and valency factors. In binary systems, some phases are exactly stoichiometric. Other systems have a narrow compositional range not containing the composition of their formula (e.g., CuAl_2).

Intermetallics in Al

Some phases have a wide compositional range.

Intermetallics of transitional metals often have a succession of well-defined phases and may have complex stoichiometry (e.g., MnAl_6 , MnAl_4 and MnAl_3). Transition metal intermetallics are often metastable, one phase formed during rapid solidification transforms to another in the solid state (e.g., FeAl_6 forming FeAl_3).

Preparation of Aluminium Specimens

- Grind with 240-grit SiC water-cooled paper, 240 rpm, 5 lbs. (20N) per specimen, until co-planar
- Polish with 9- μm Diamond on an Ultra-Pol (silk) cloth, 150 rpm, 5 lbs/specimen, 5 minutes (contra rotation)
- Polish with 3- μm Diamond on a Trident cloth, 150 rpm, 5 lbs/specimen, 4 minutes (contra rotation)
- Polish with 1- μm Diamond on a Trident cloth, 150 rpm, 5 lbs/specimen, 3 minutes (contra rotation)
- Polish with 0.05- μm Colloidal Silica on a Microcloth pad, 120 rpm, 5 lbs/specimen, 3 minutes (contra rotation)

(Contra: Head and platen rotate in opposite directions)

Standard “Black&White” Etchants for Aluminium

- **Keller's Reagent**

95 mL water, 2.5 mL HNO_3 ,
1.5 mL HCl , 1.0 mL HF – Immerse

- **Caustic Sodium Fluoride Etch**

93 mL water, 2 g NaOH , 5 g NaF

- **Graff-Sargent Etch**

84 mL water, 15.5 mL HNO_3 ,
0.5 mL HF , 3 g CrO_3

Color “Tint Etching” With Weck’s Reagent

100 mL water

4 g KMnO_4

1 g NaOH

Immerse up to 20 s

Works better on cast Al than wrought Al

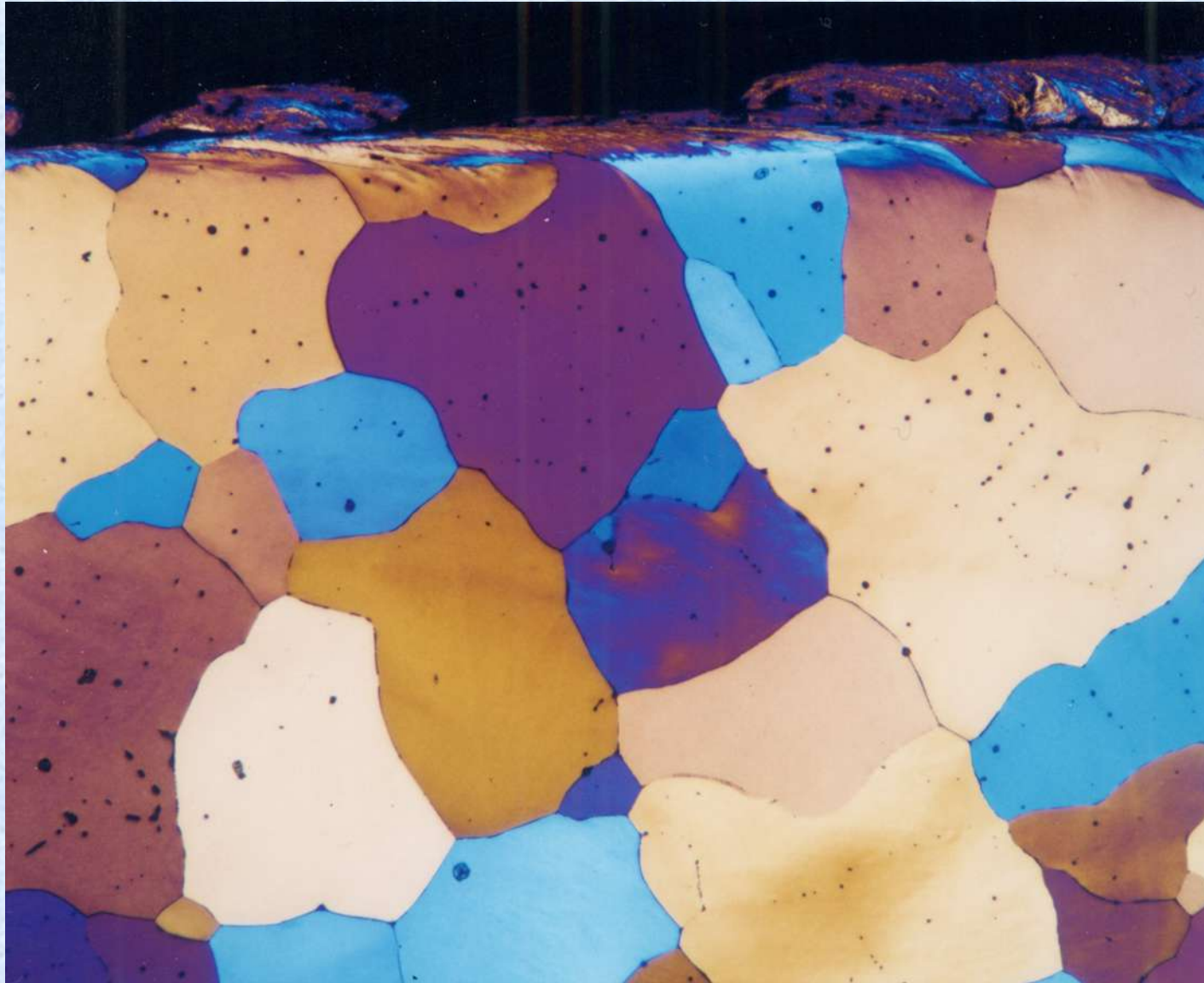
Anodizing with Barker's Reagent

1.8% Fluoboric acid in water

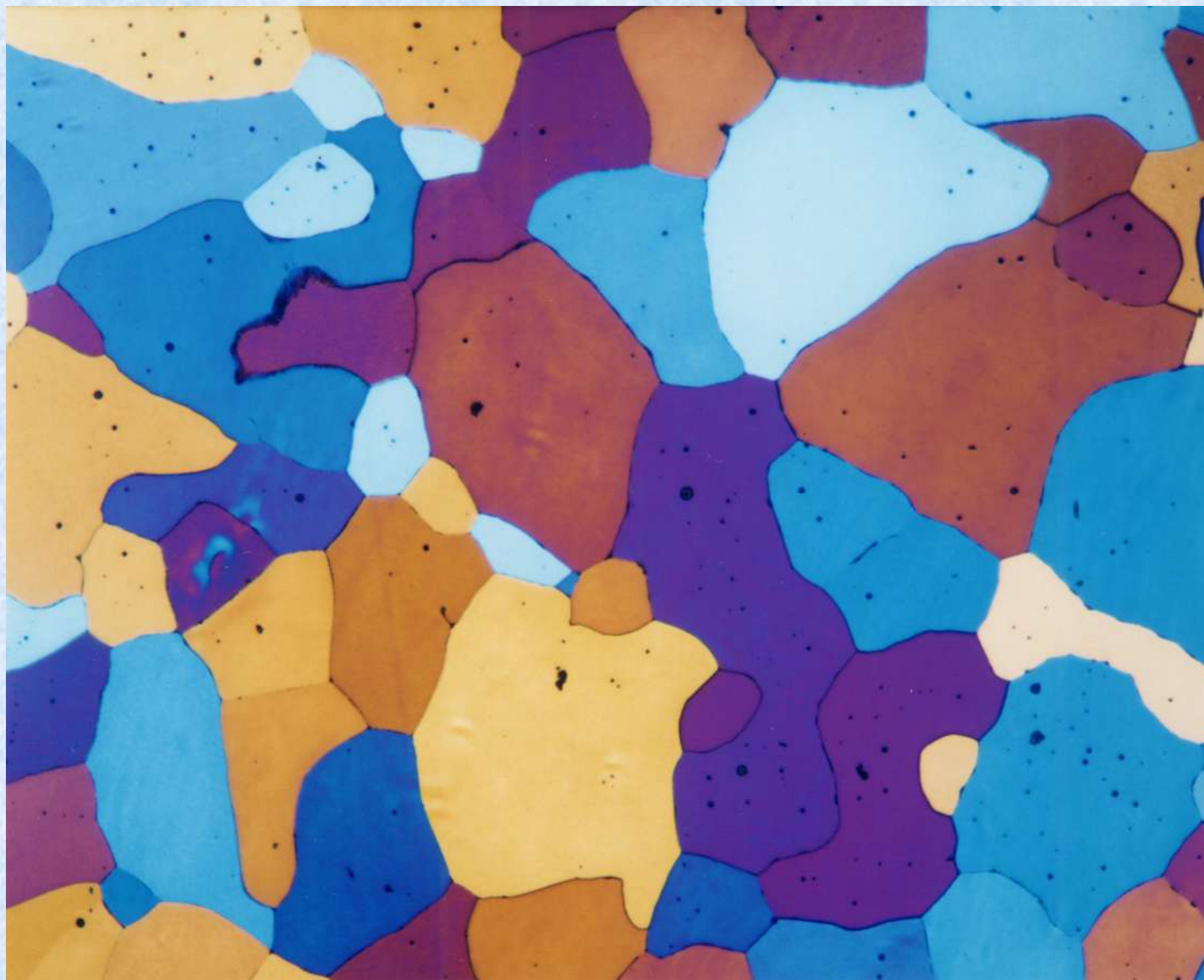
20-45 V dc, for up to 2 minutes

Examine with crossed polarized light, plus a sensitive tint (first order red plate, or λ plate) to see the microstructure in color. It is good for grain size, but does not reveal alloy segregation.

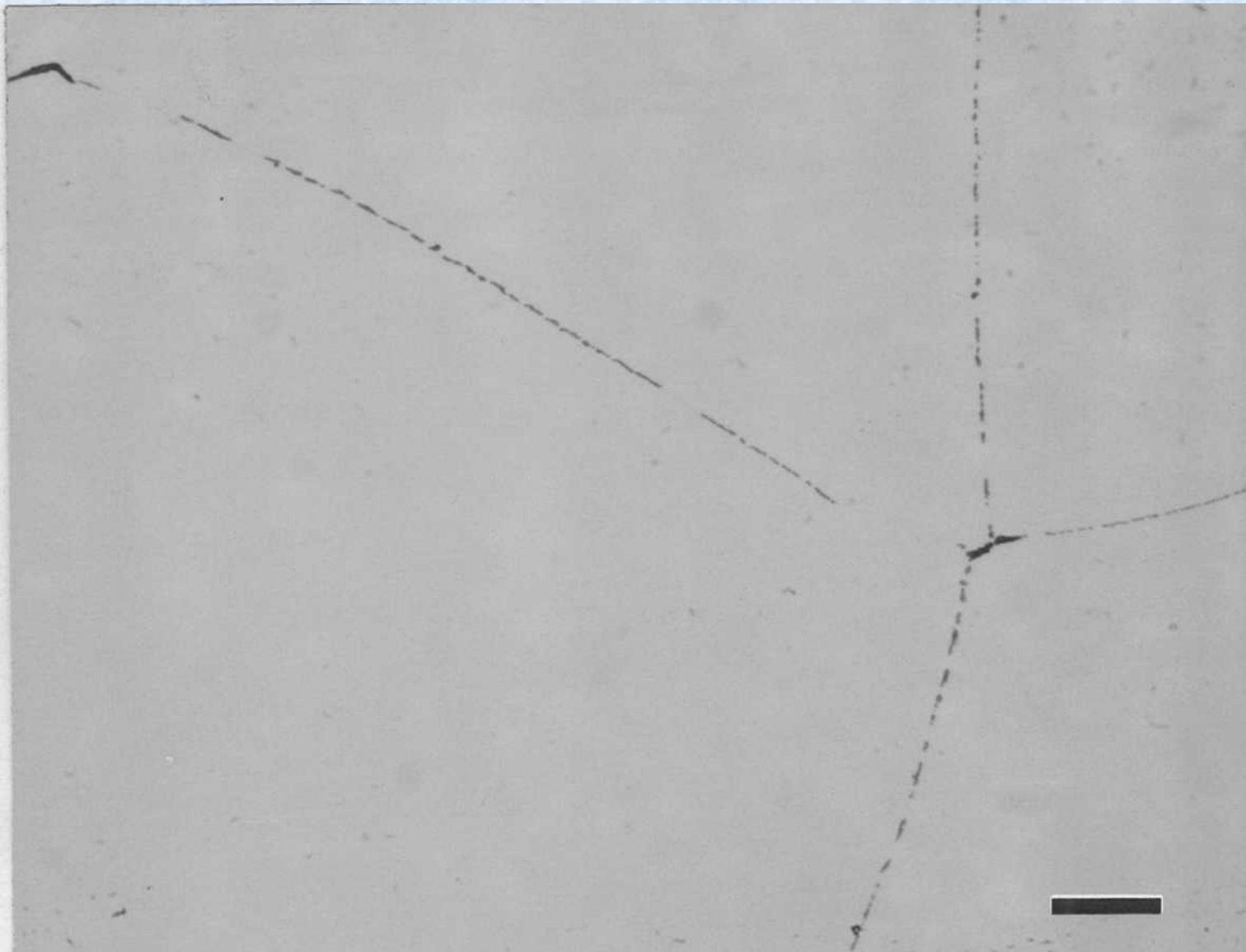
Wrought Alloys



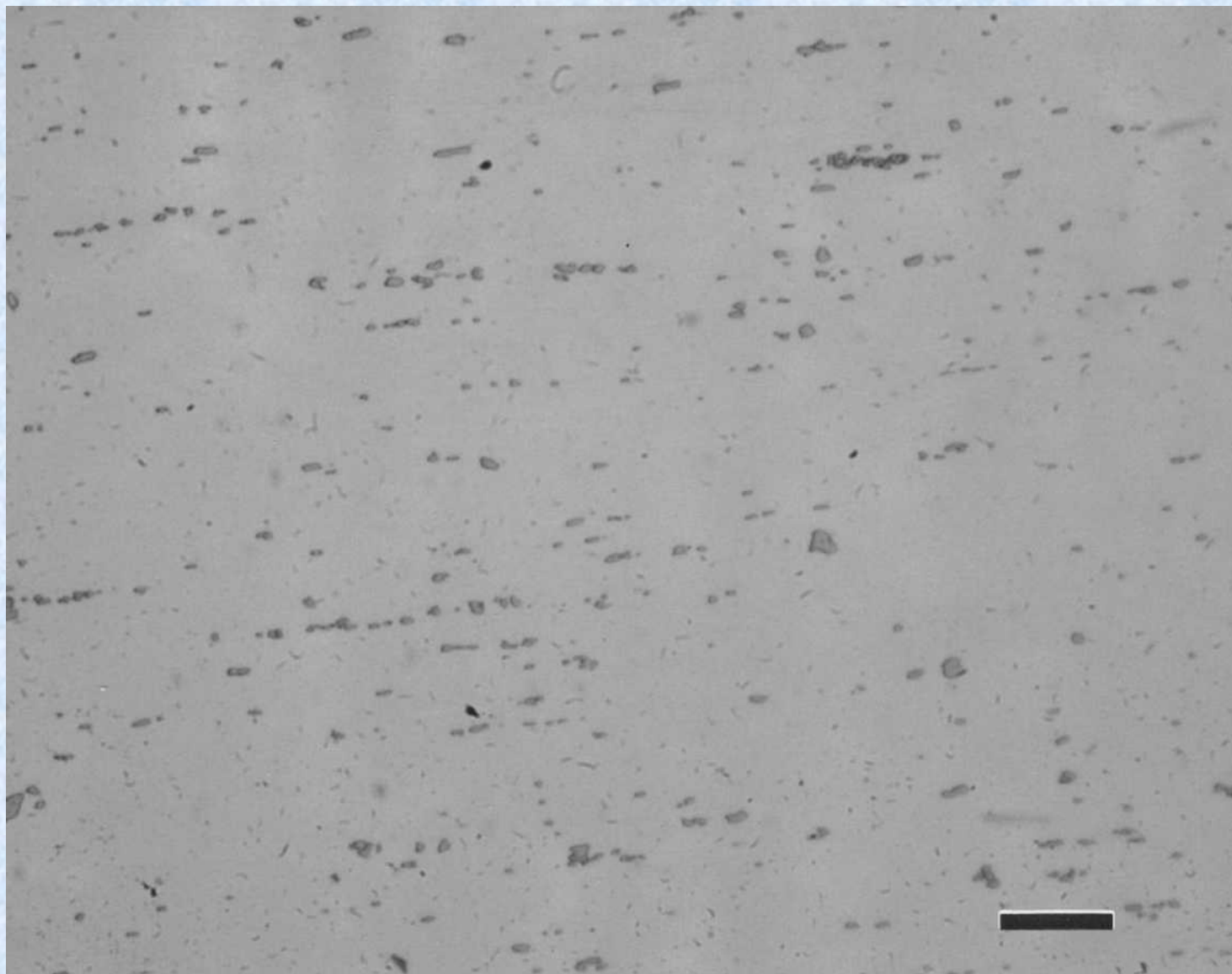
Equiaxed alpha grains at the surface of a super-pure (SP) aluminum specimen anodized with Barker's reagent, 30 V dc, 2 min. Note the damage from sectioning along the surface (top edge). Viewed with crossed polars + sensitive tint. Original at 50X.



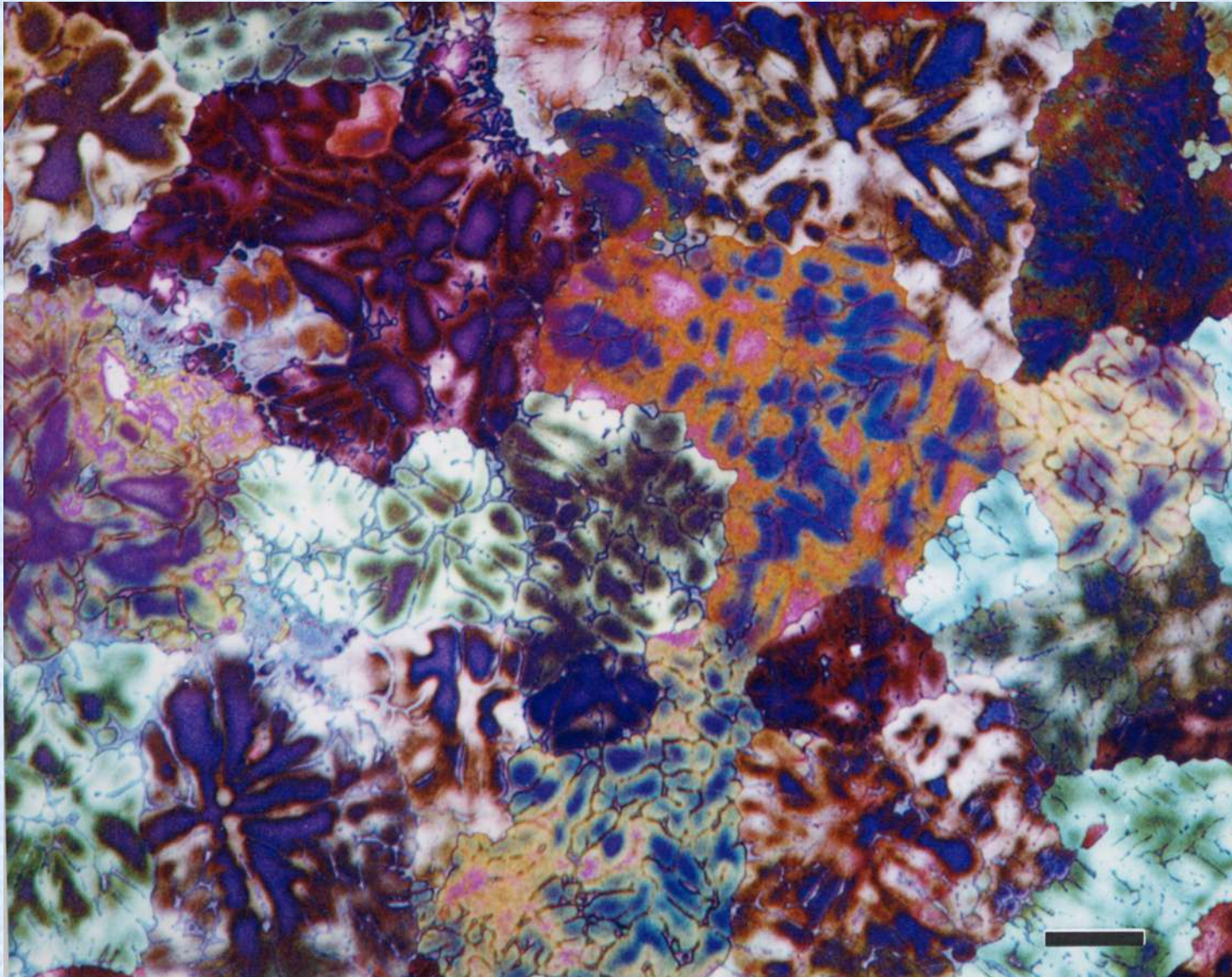
Equiaxed alpha grains in the interior of a super-pure aluminum specimen anodized with Barker's reagent, 30 V dc, 2 min. Viewed with crossed polars + sensitive tint. Original at 50X. The dark spots are intermetallic phases.



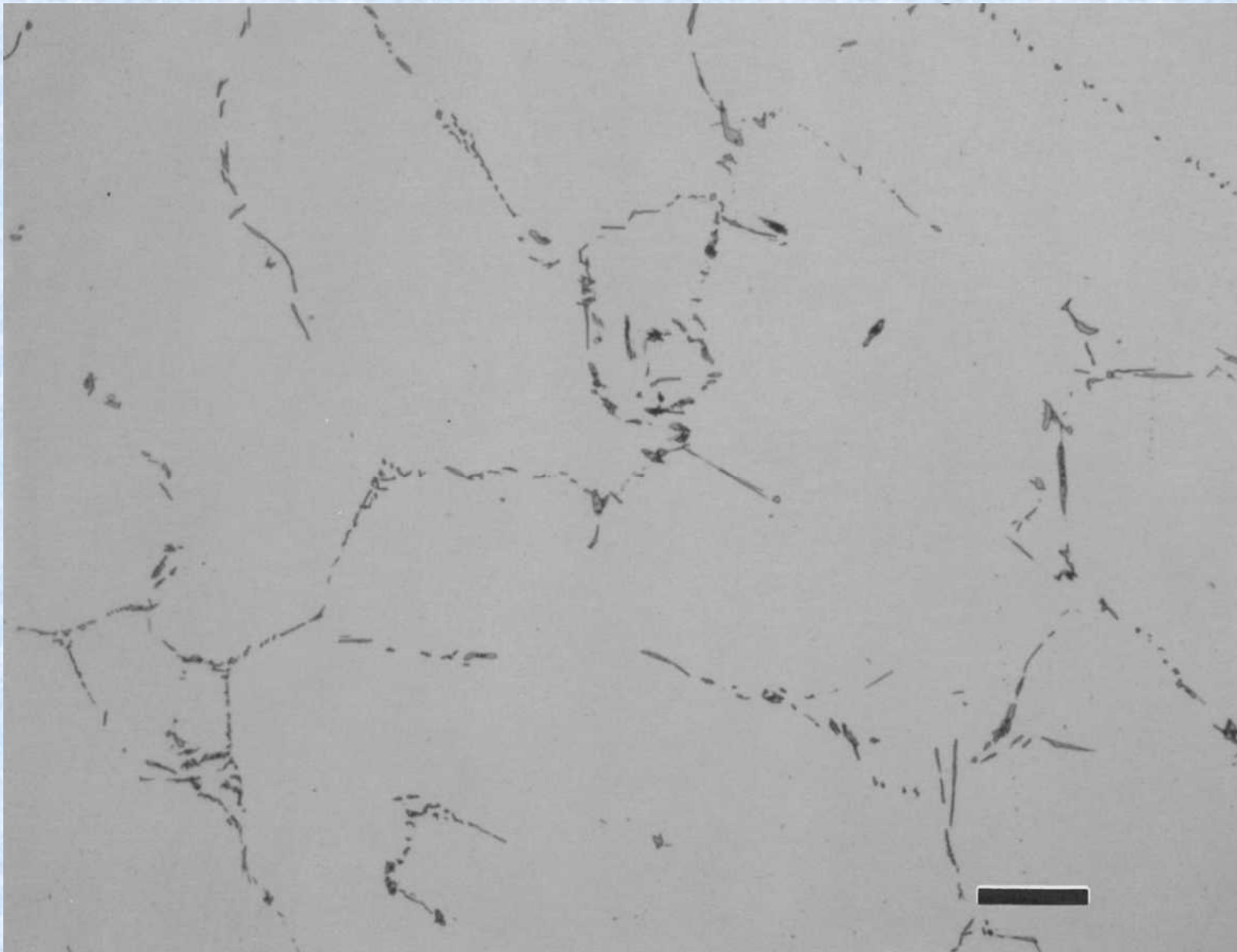
Grain boundary precipitates in super-pure aluminum specimen (shown previously) revealed by aqueous 0.5% HF etch. Magnification bar is 20 μm long.



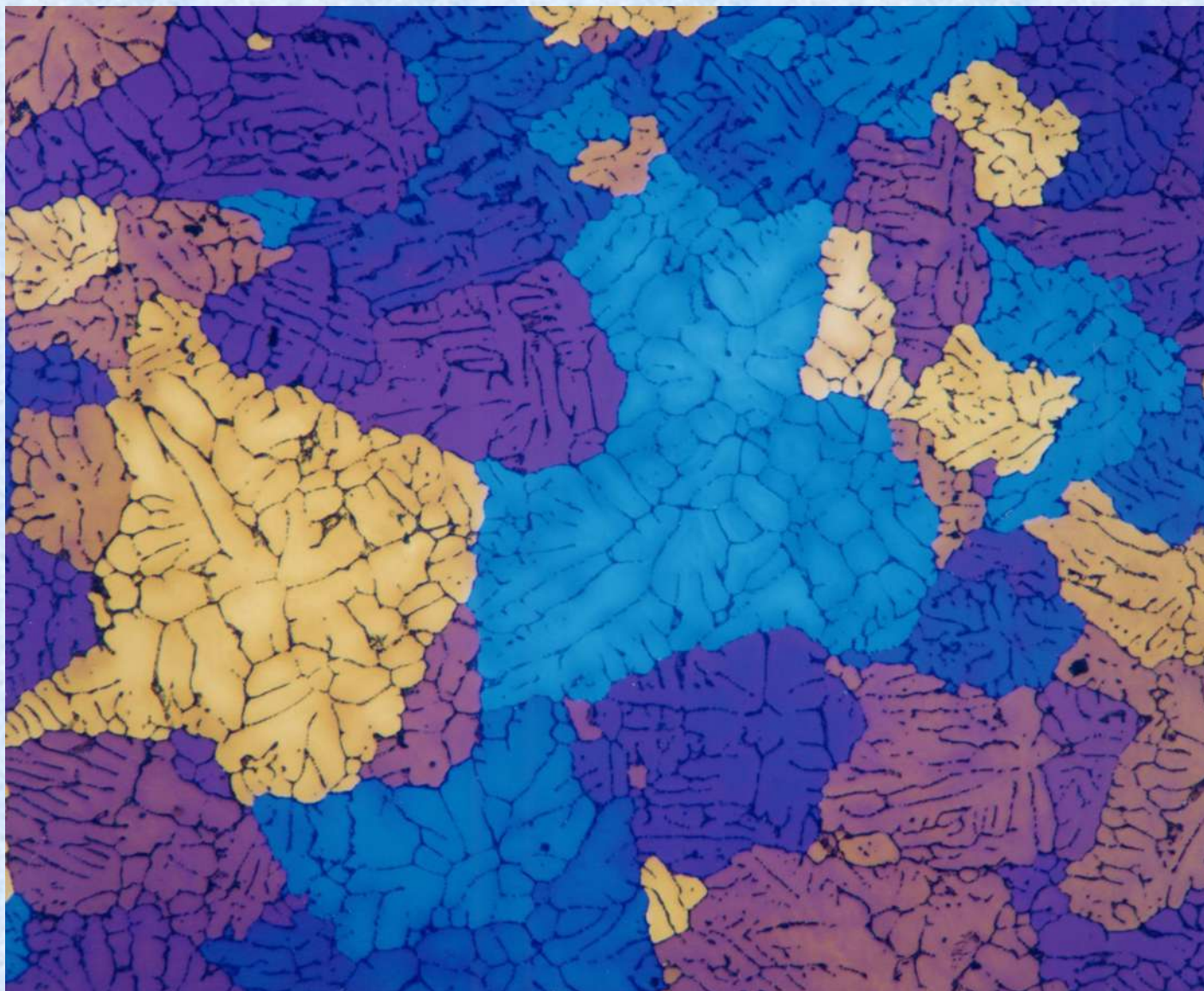
Extruded commercial-purity (CP) aluminum, >99% Al, (deformation axis horizontal). Aqueous 0.5% HF etch. Magnification bar is 10 μm long.



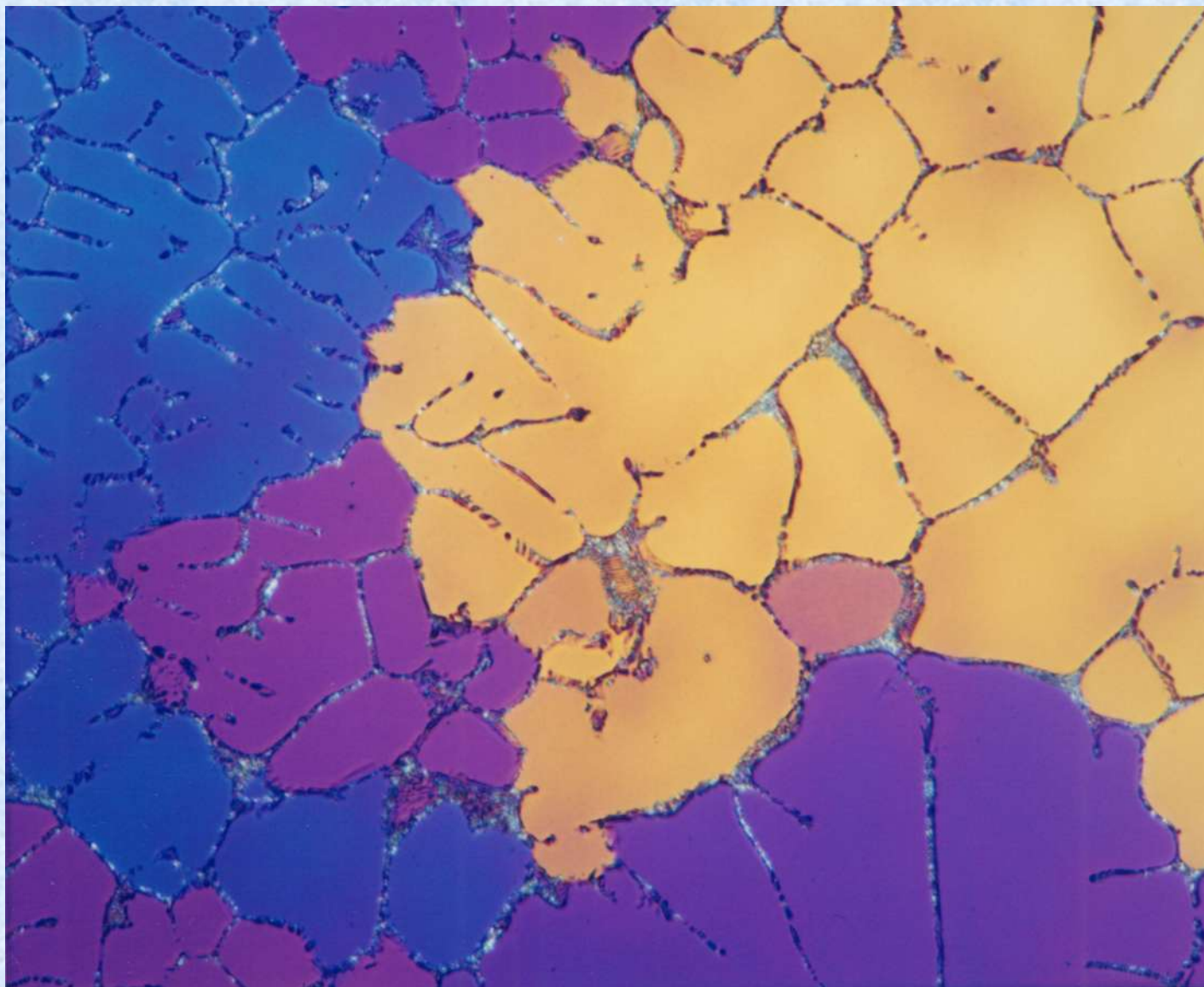
As-cast (concast) 1100 Al (>99% Al) tint etched with Weck's reagent revealing a dendritic solidification structure. Magnification bar is 200 μm long.. Viewed with crossed polars + sensitive tint.



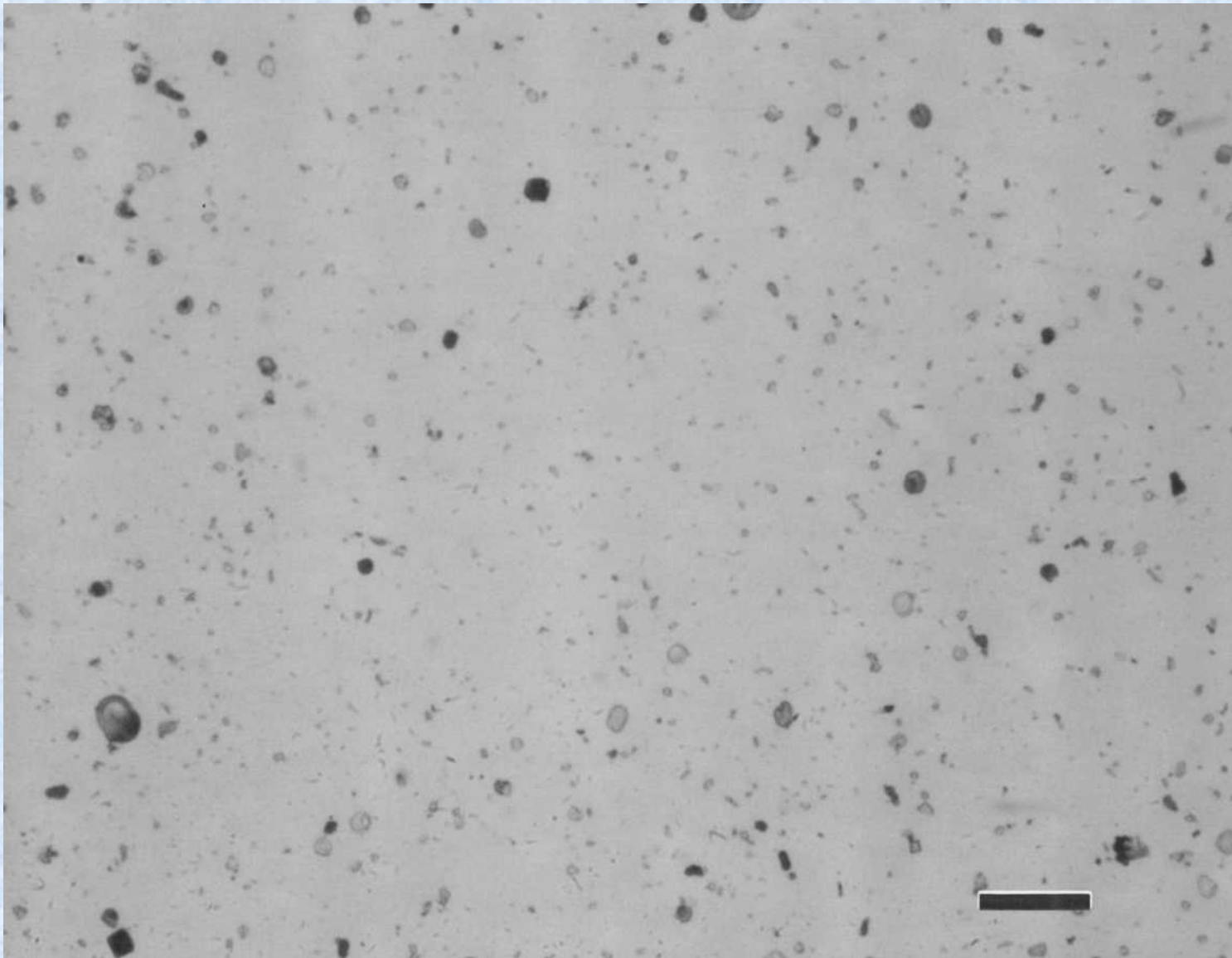
As-cast (concast) 1100 Al (>99% Al) etched with Keller's reagent revealing intermetallics in the interdendritic regions. Magnification bar is 50 μm long.



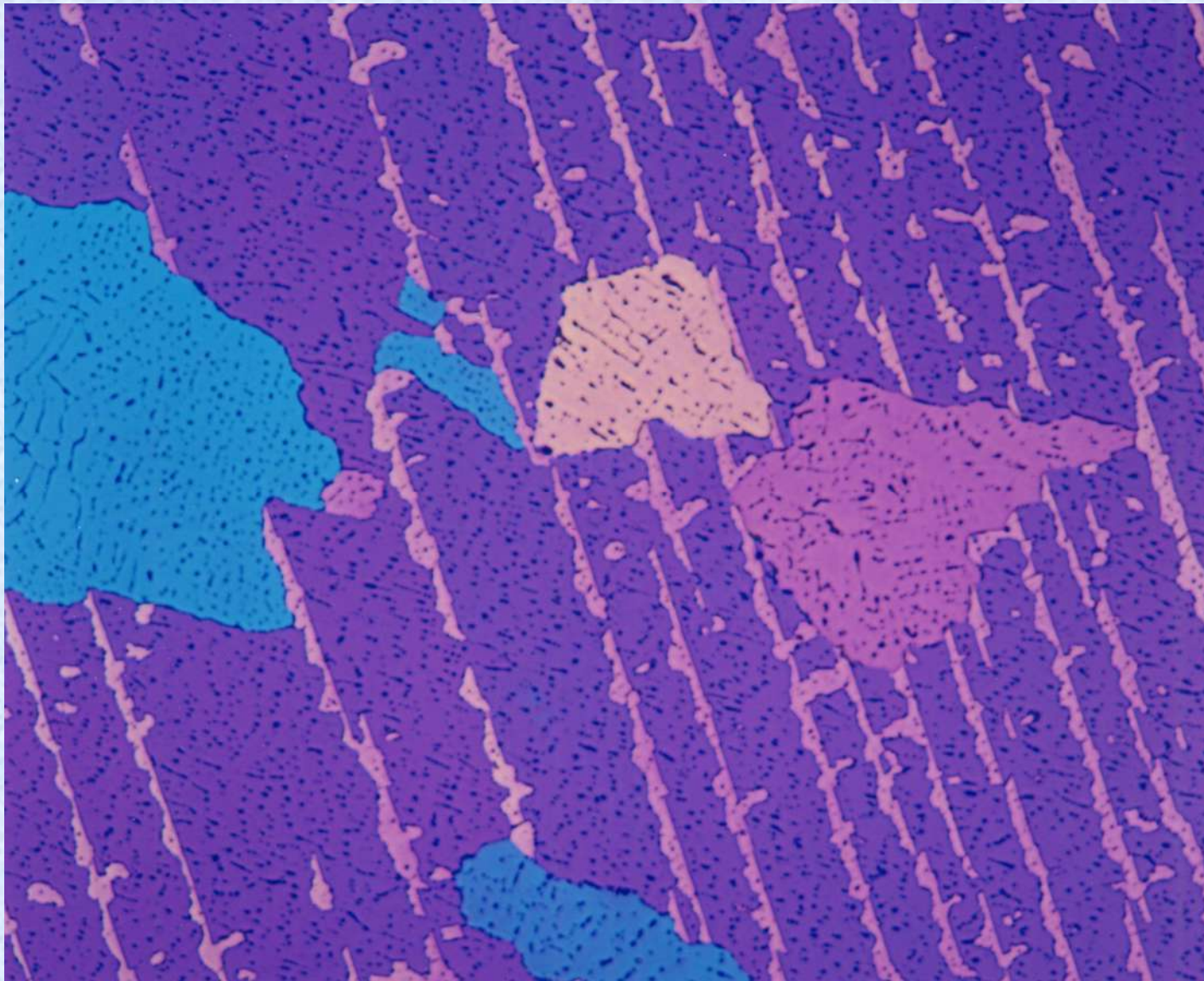
As-cast (concast) 1100 Al (>99% Al) anodized with Barker's reagent (30 V dc, 2 min.) revealing a dendritic solidification structure. Original at 50X. Viewed with crossed polars + sensitive tint.



As-cast (concast) 1100 Al (>99% Al) anodized with Barker's reagent (30 V dc, 2 min.) revealing a dendritic solidification structure and intermetallics in the interdendritic areas. Original at 200X. Viewed with crossed polars + sensitive tint.

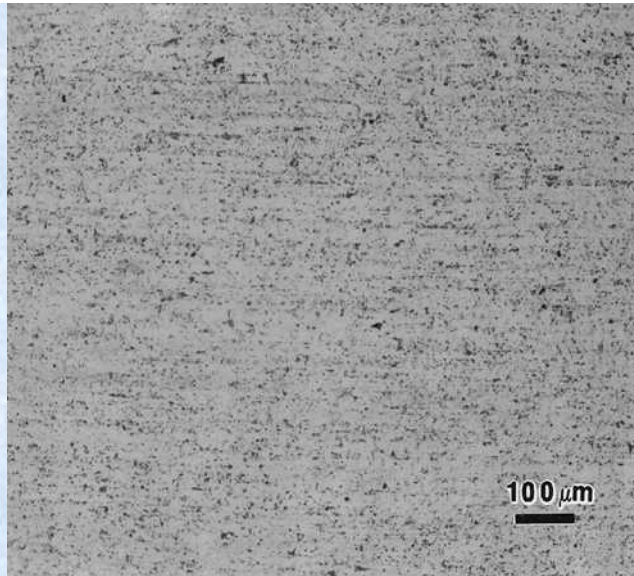


Wrought 1100 aluminum (>99% Al) etched with aqueous 0.5% HF. Magnification bar is 10 μm long.

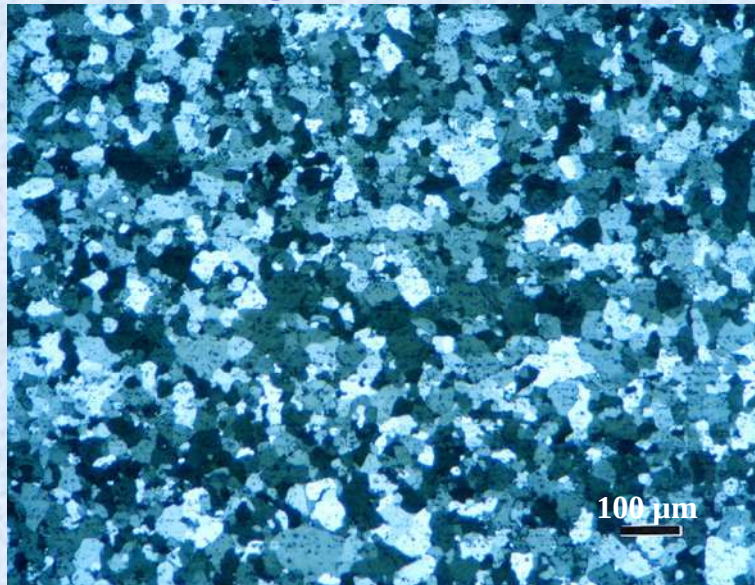


**Wrought 1100 aluminum (>99% Al) anodized with Barker's reagent (20 V dc, 2 min.).
Original at 50X. Viewed with crossed polarized light plus sensitive tint.**

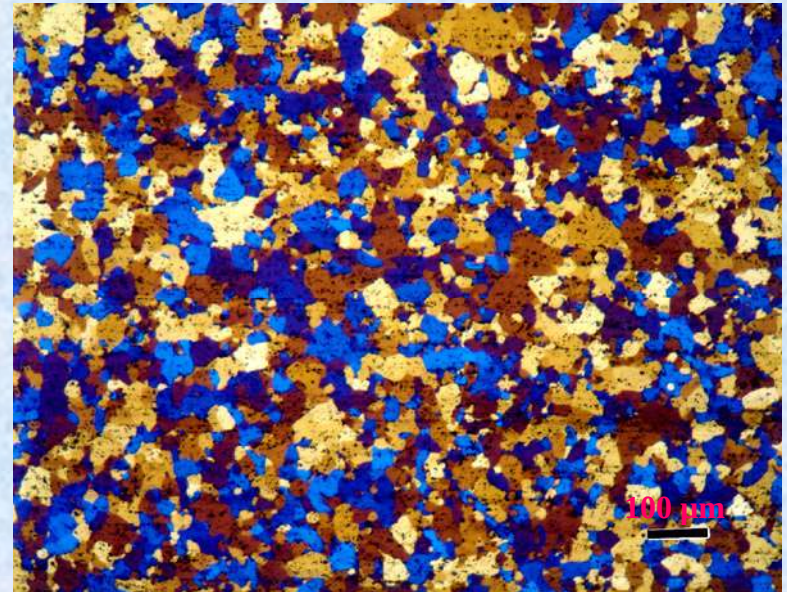
Bright Field



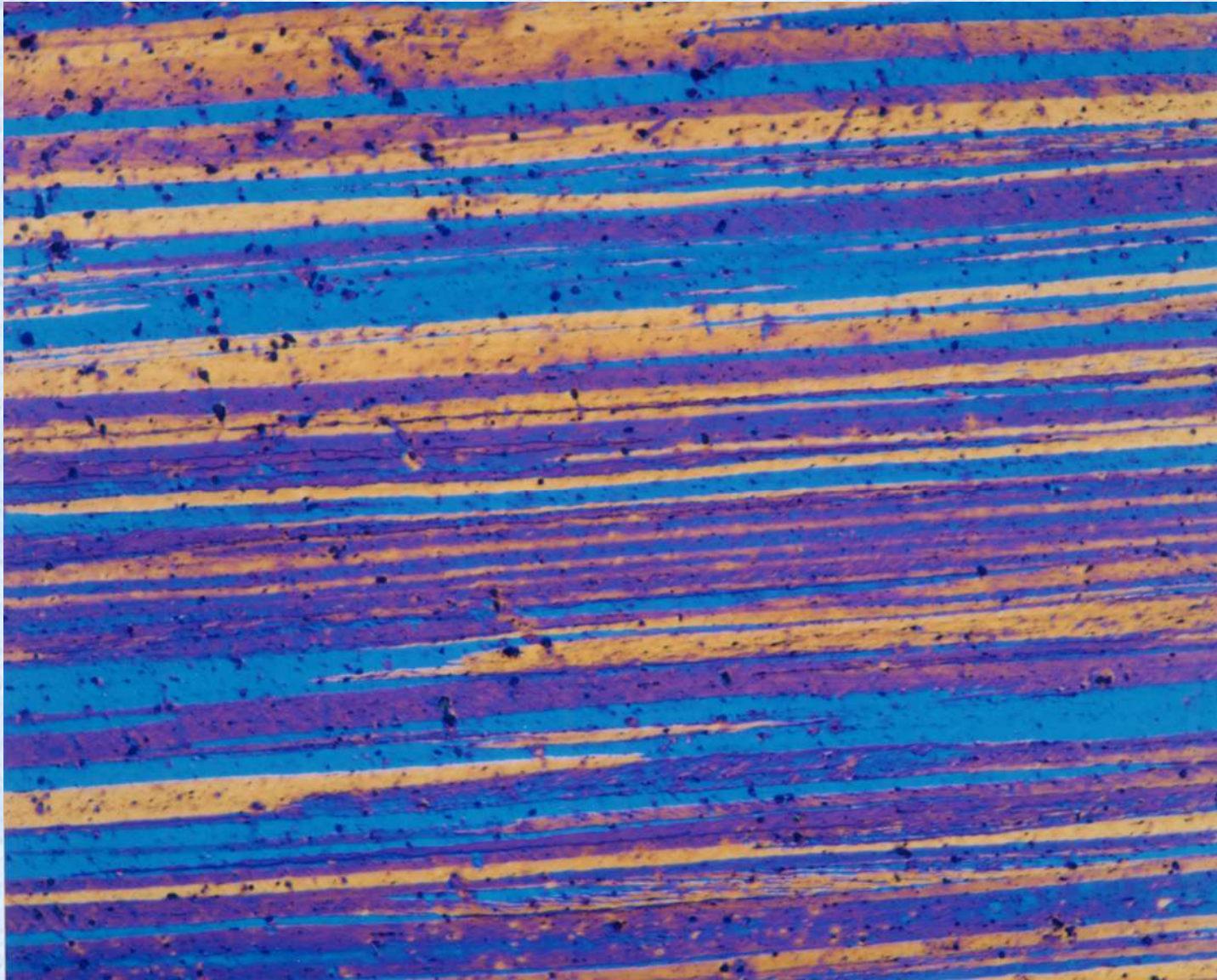
Polarized Light



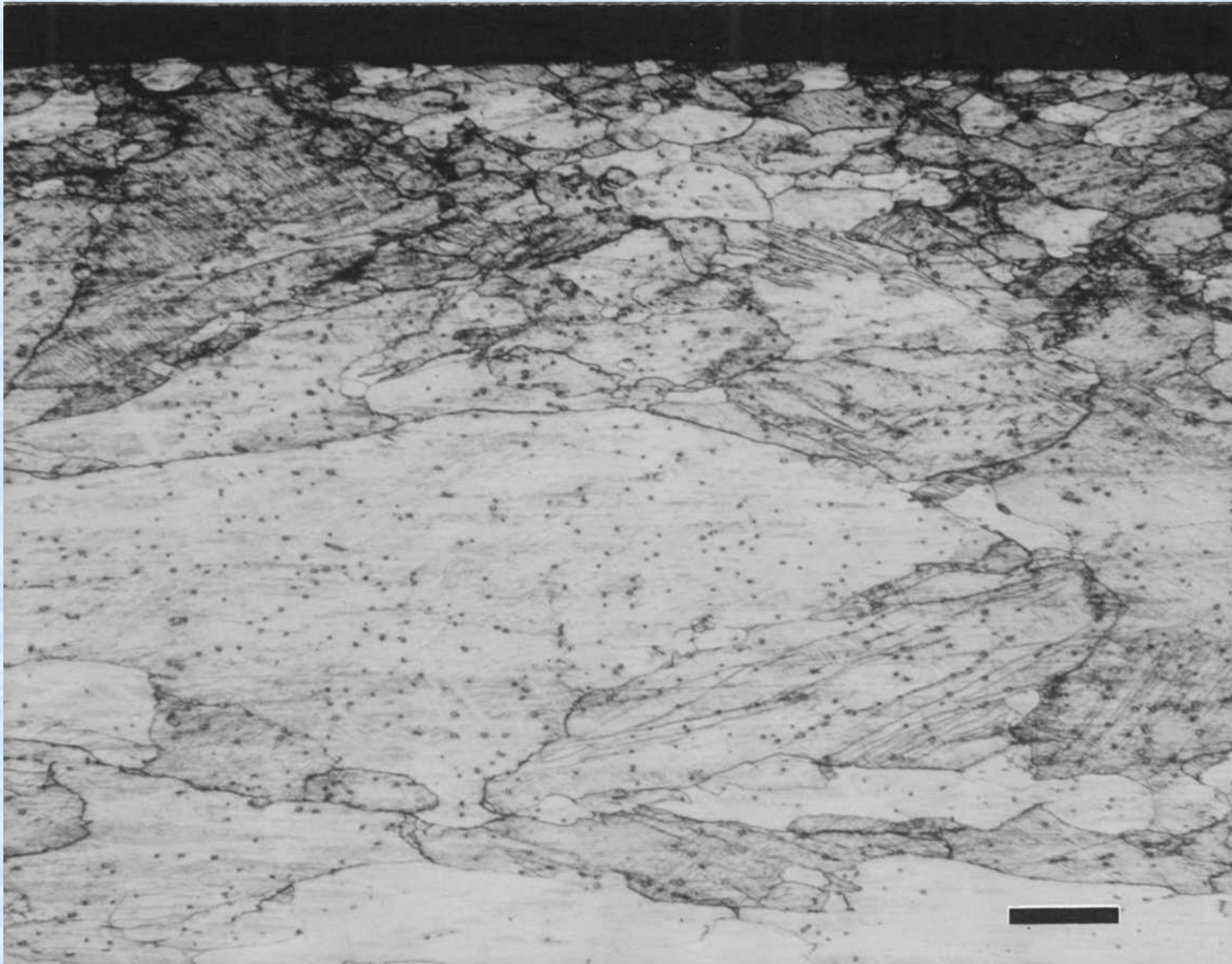
PL + Sensitive Tint



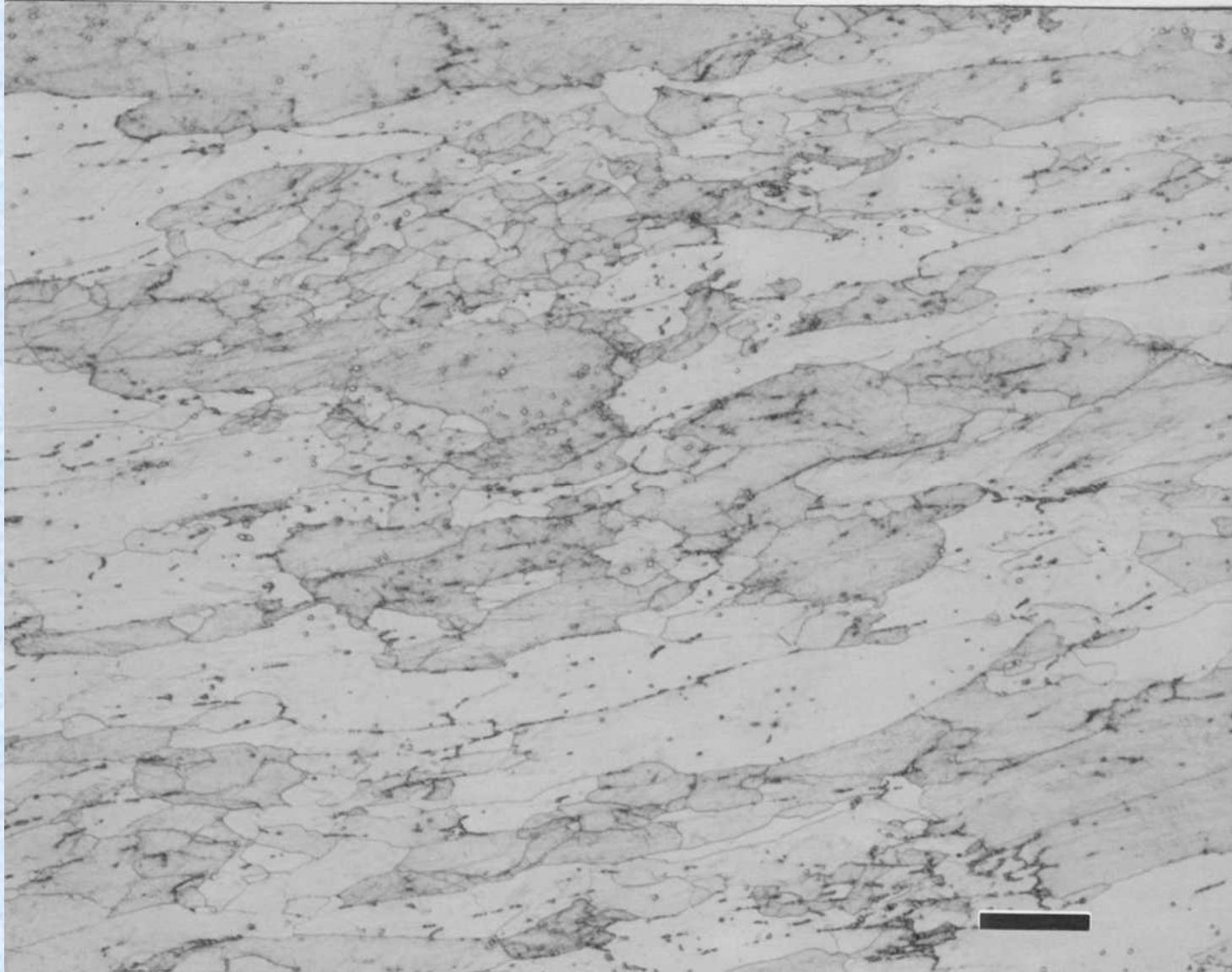
Grain structure of wrought 1100 grade foil after electrolytic polishing and anodizing with Barker's reagent (20 V dc, 2 min), and viewed with bright field (top), polarized light (left) and with polarized light plus a sensitive tint filter (right). Note that color is not observed in bright field because an interference film is not formed using Barker's reagent.



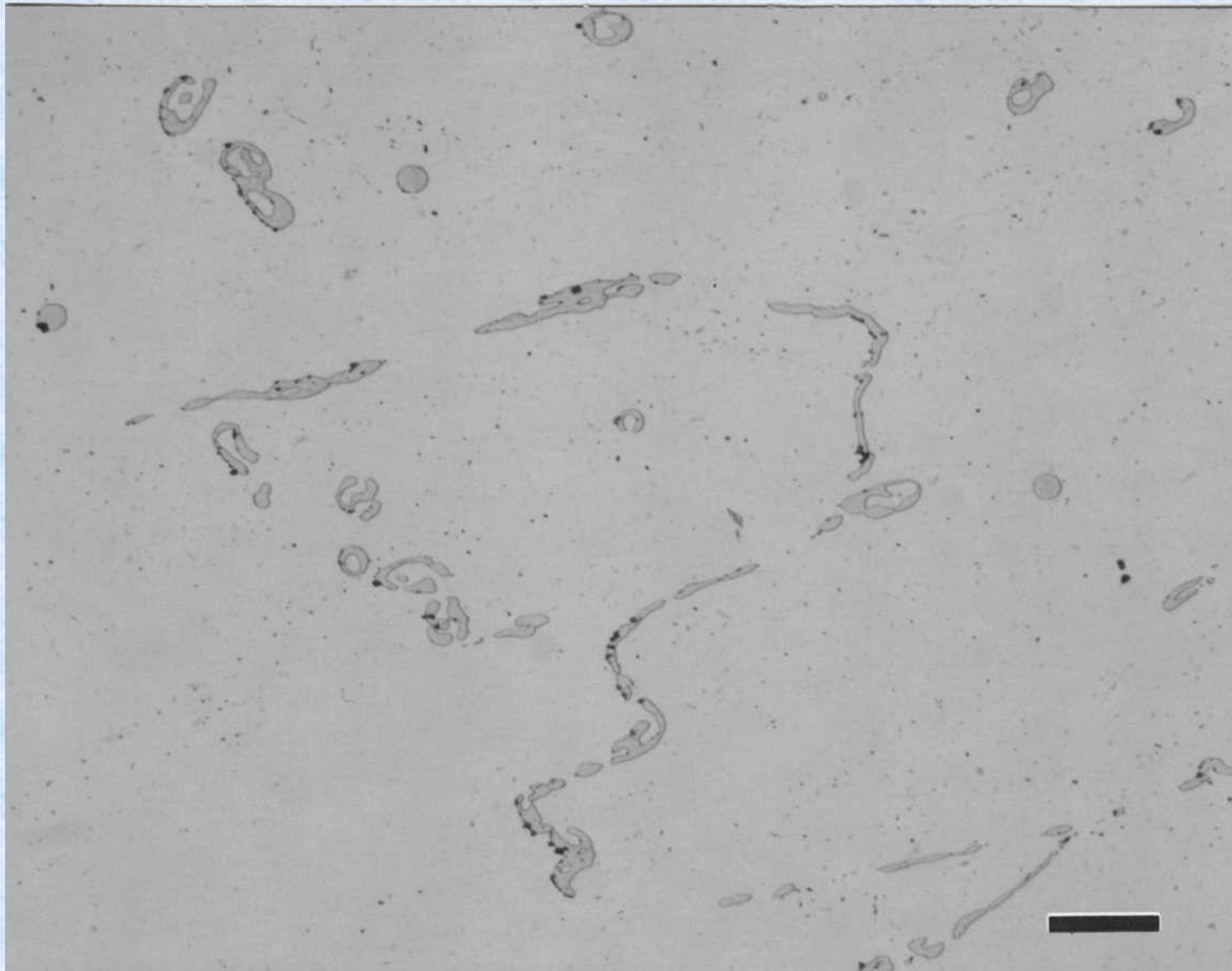
Wrought (extruded) 1350 aluminum (>99.5% Al) anodized with Barker's reagent (20 V dc, 2 min.) and viewed with crossed polarized light plus sensitive tint. Note the highly elongated alpha grain structure. Original at 50X.



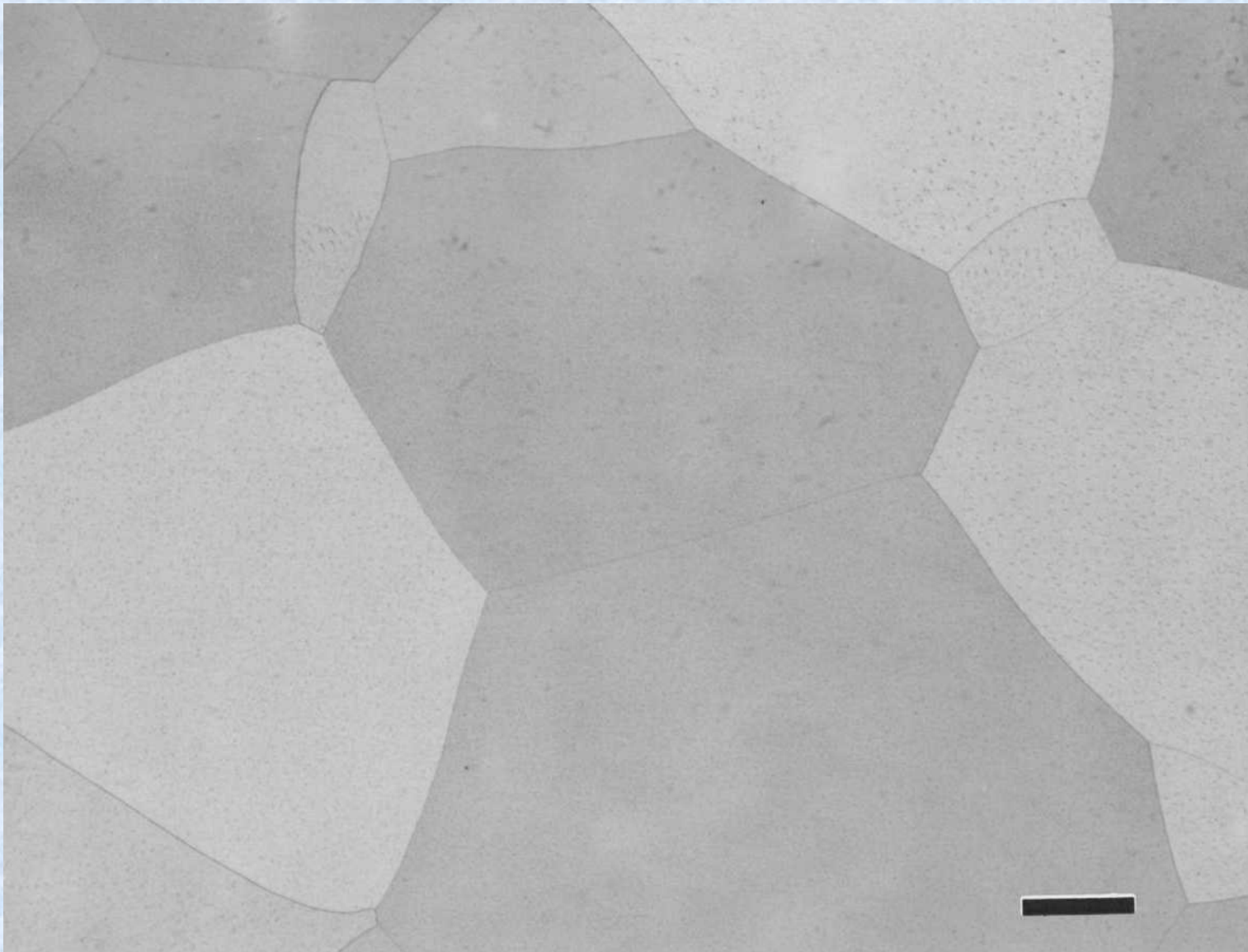
Surface grain structure of as-hot worked Al – 4% Cu showing non-recrystallized grain structure at the surface and fine θ'' precipitates. Keller's reagent. Magnification bar is 200 μm long.



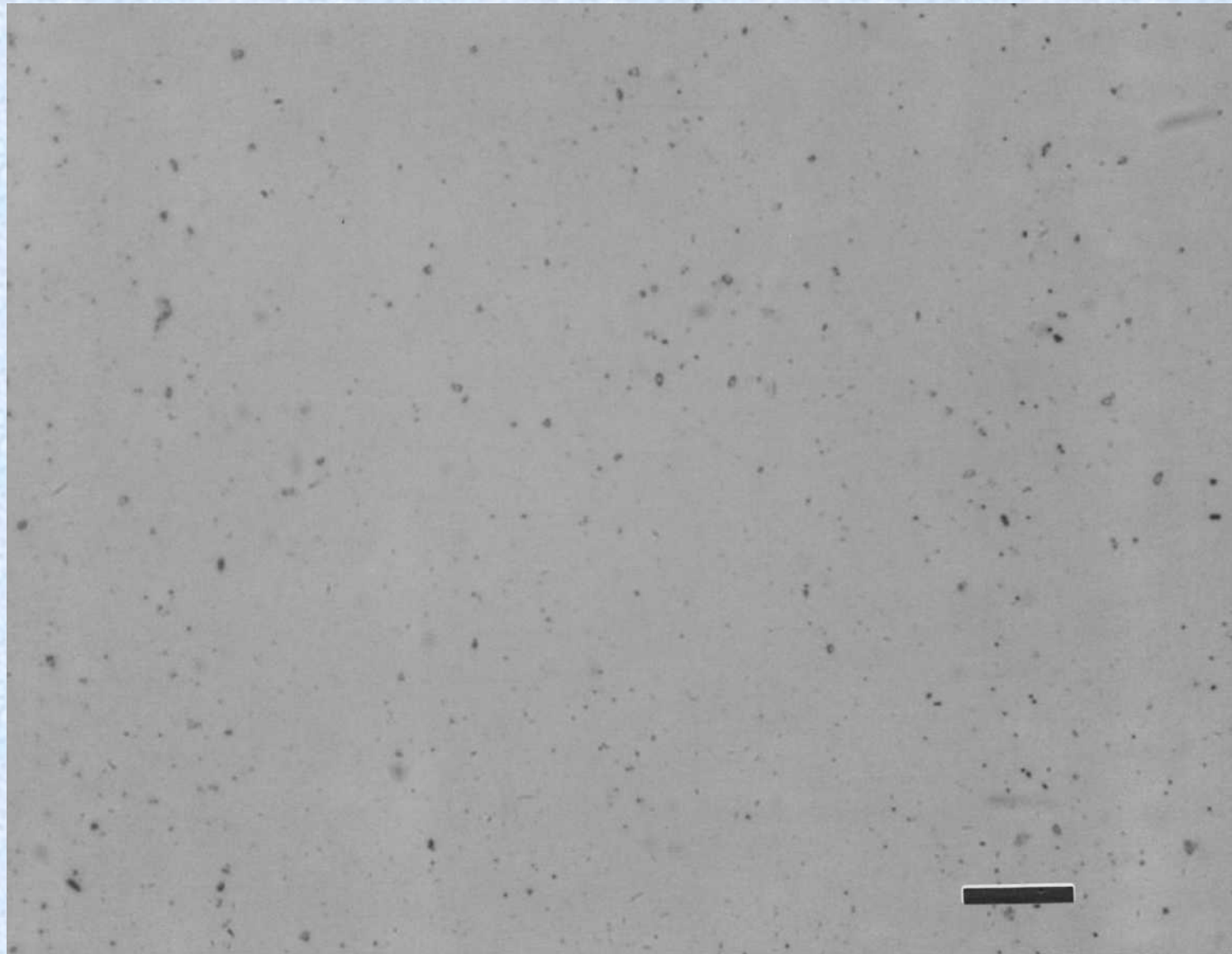
Interior grain structure of as-hot worked Al – 4% Cu showing elongated, non-recrystallized grain structure θ precipitates. Keller's reagent. Magnification bar is 200 μm long.



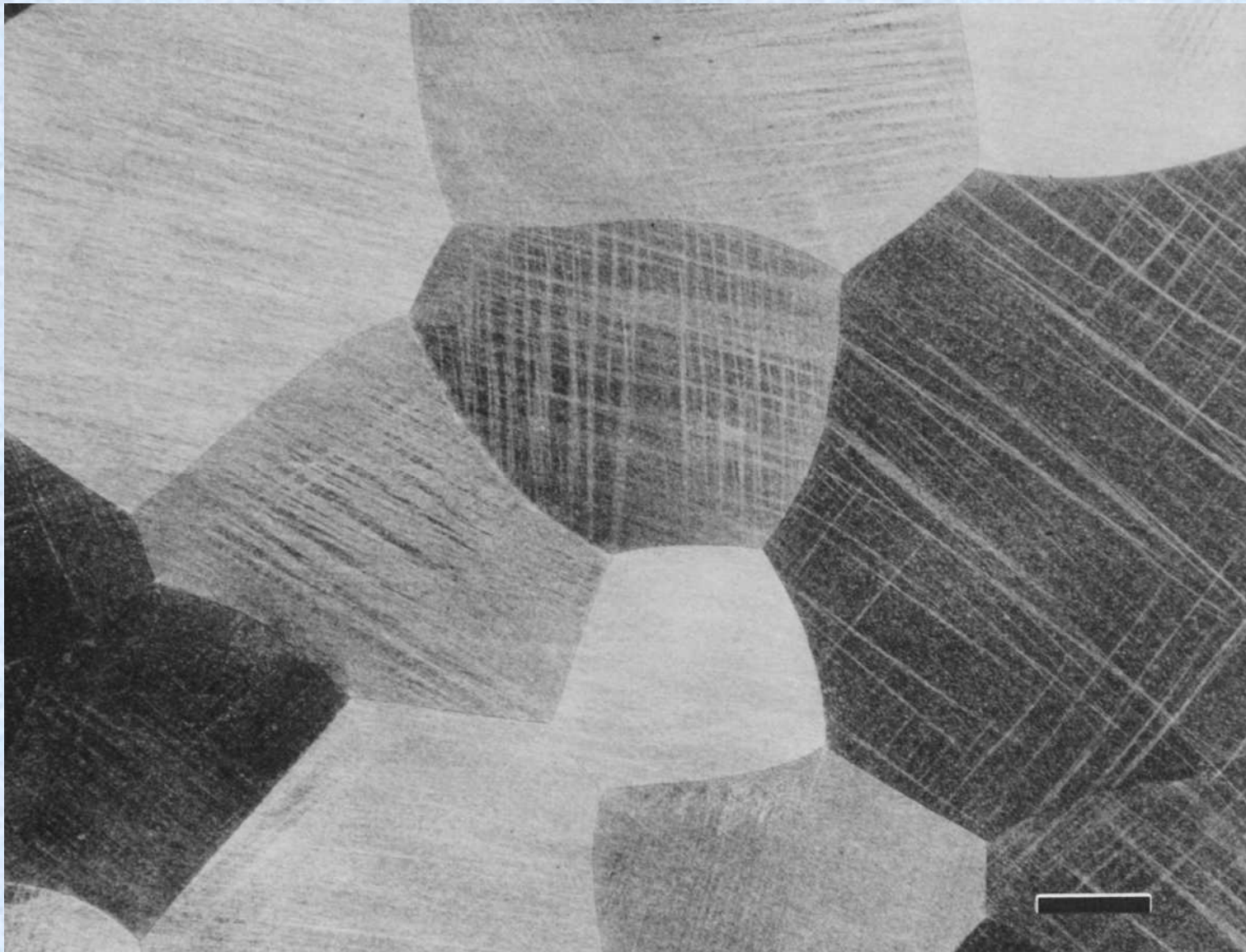
Interior of as-hot worked Al – 4% Cu showing fine theta-phase precipitates. Etched with aqueous 0.5% HF. Magnification bar is 20 μm long.



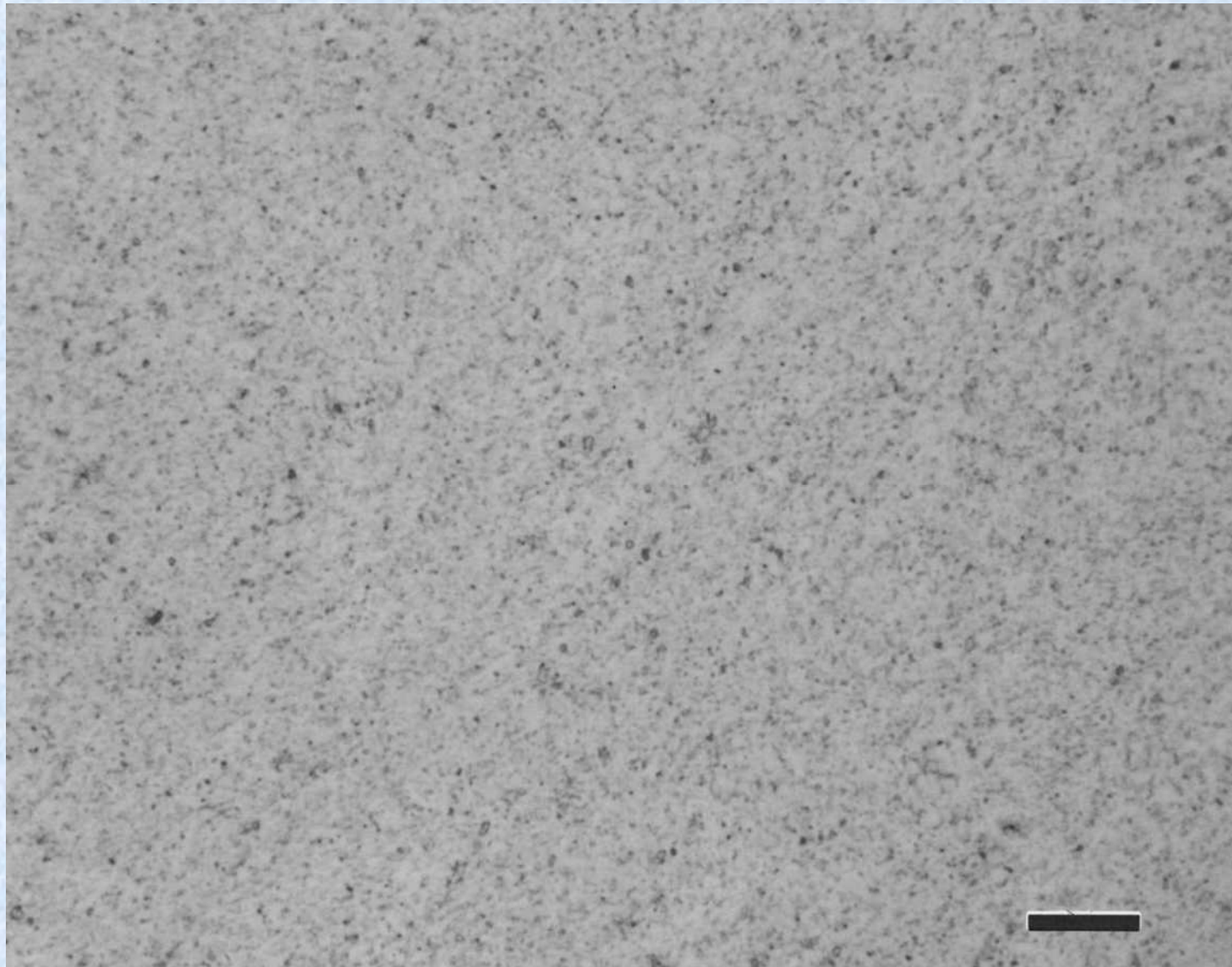
**Equiaxed alpha grain structure in solution annealed (552 °C, 1025 °F for 1 h, water quench)
Al – 4 % Cu etched with Keller's reagent. Magnification bar is 200 μm long.**



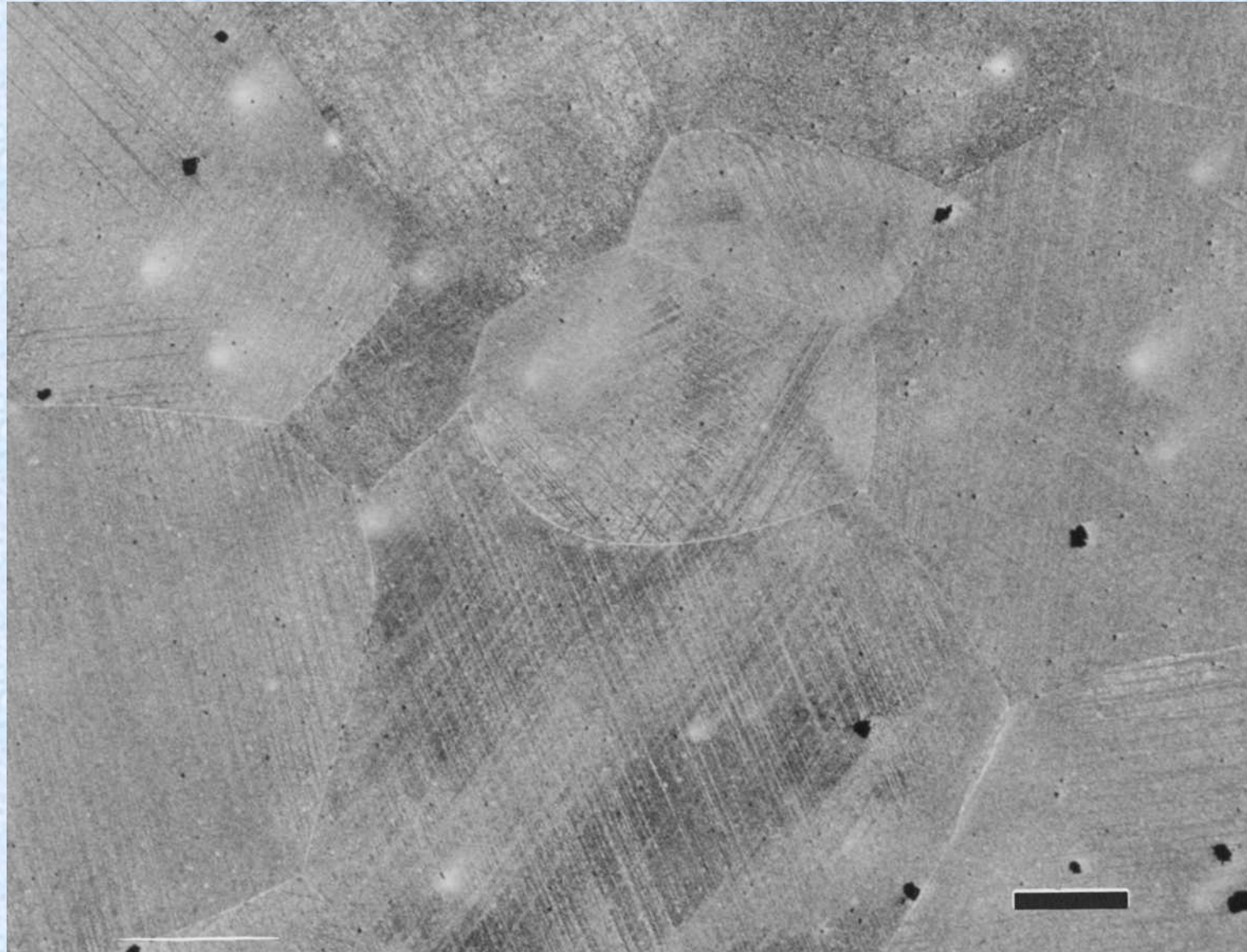
Fine precipitates remaining in solution annealed (552 °C, 1025 °F for 1 h, water quench) Al – 4 % Cu etched with aqueous 0.5% HF. Magnification bar is 10 μ m long.



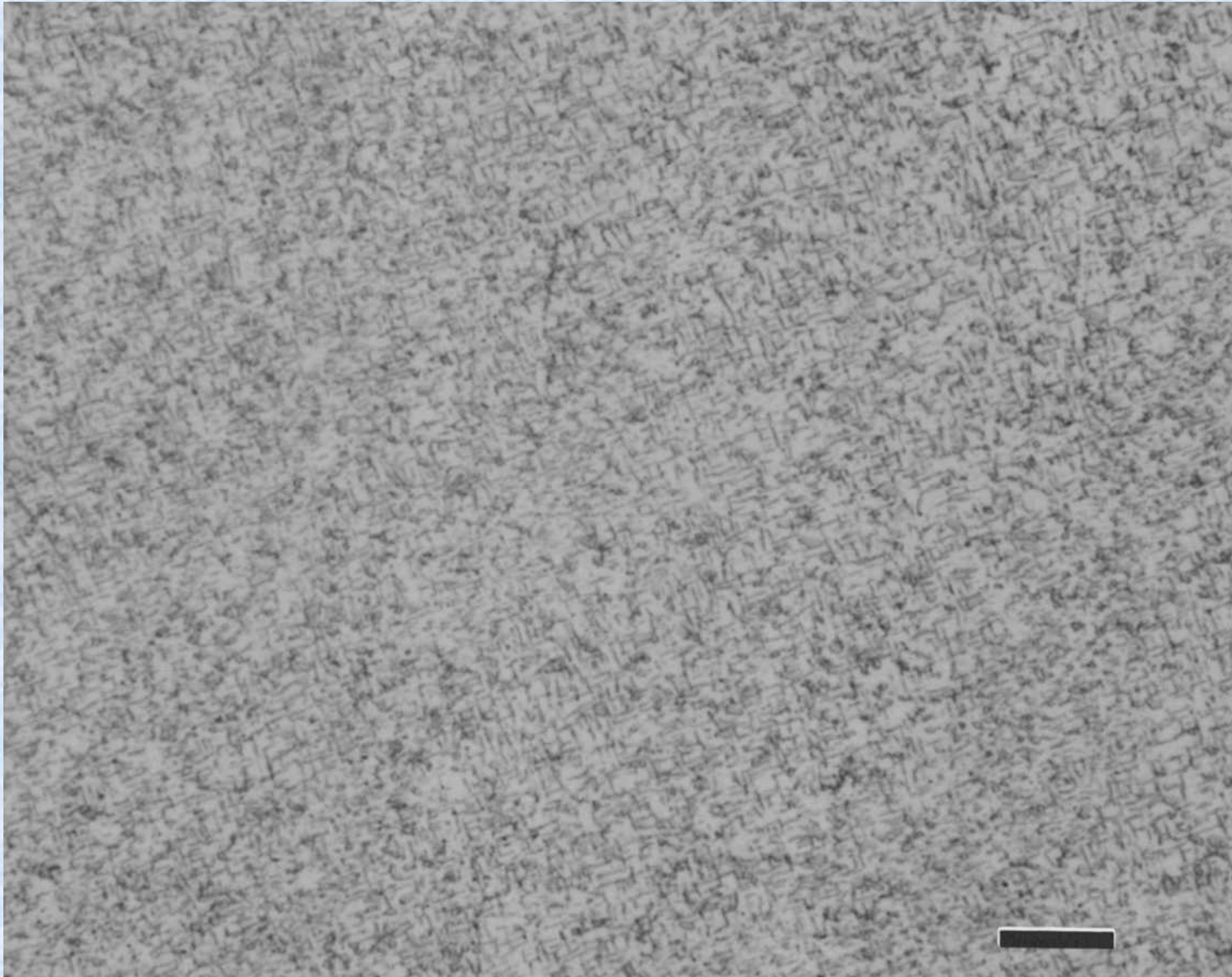
Equiaxed alpha grain structure with criss-cross marks in solution annealed and aged (552 °C, 1025 °F for 1 h, water quench, 260 °C, 500 °F – 1 h, air cool) Al – 4 % Cu etched with Keller's reagent. Bar is 200 μm . Markings are due to fine precipitation in the alpha phase.



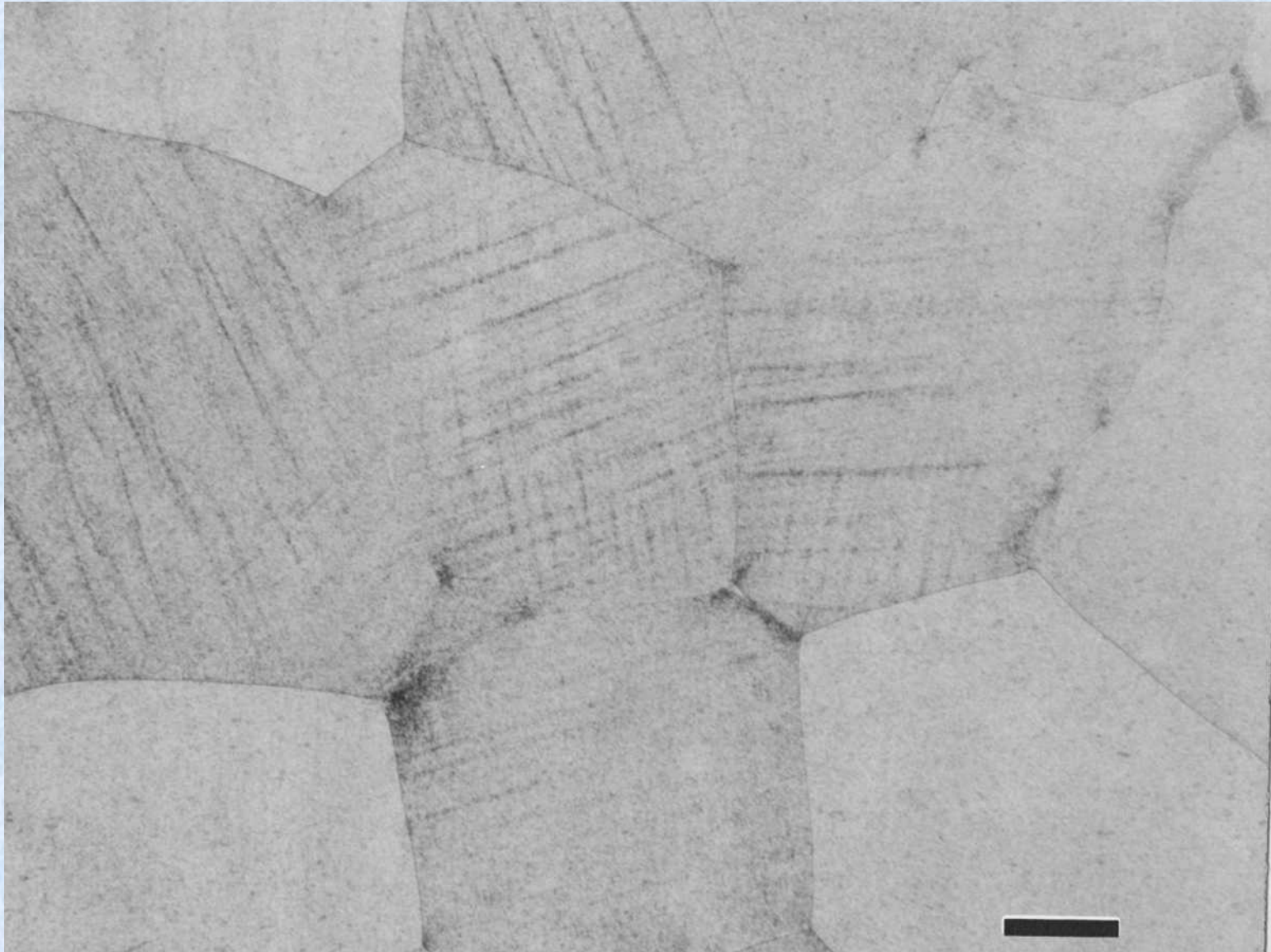
Very fine precipitates in solution annealed and aged (552 °C, 1025 °F for 1 h, water quench, 260 °C, 500 °F – 1 h, air cool) Al – 4 % Cu etched with aqueous 0.5% HF. Magnification bar is 10 μ m long.



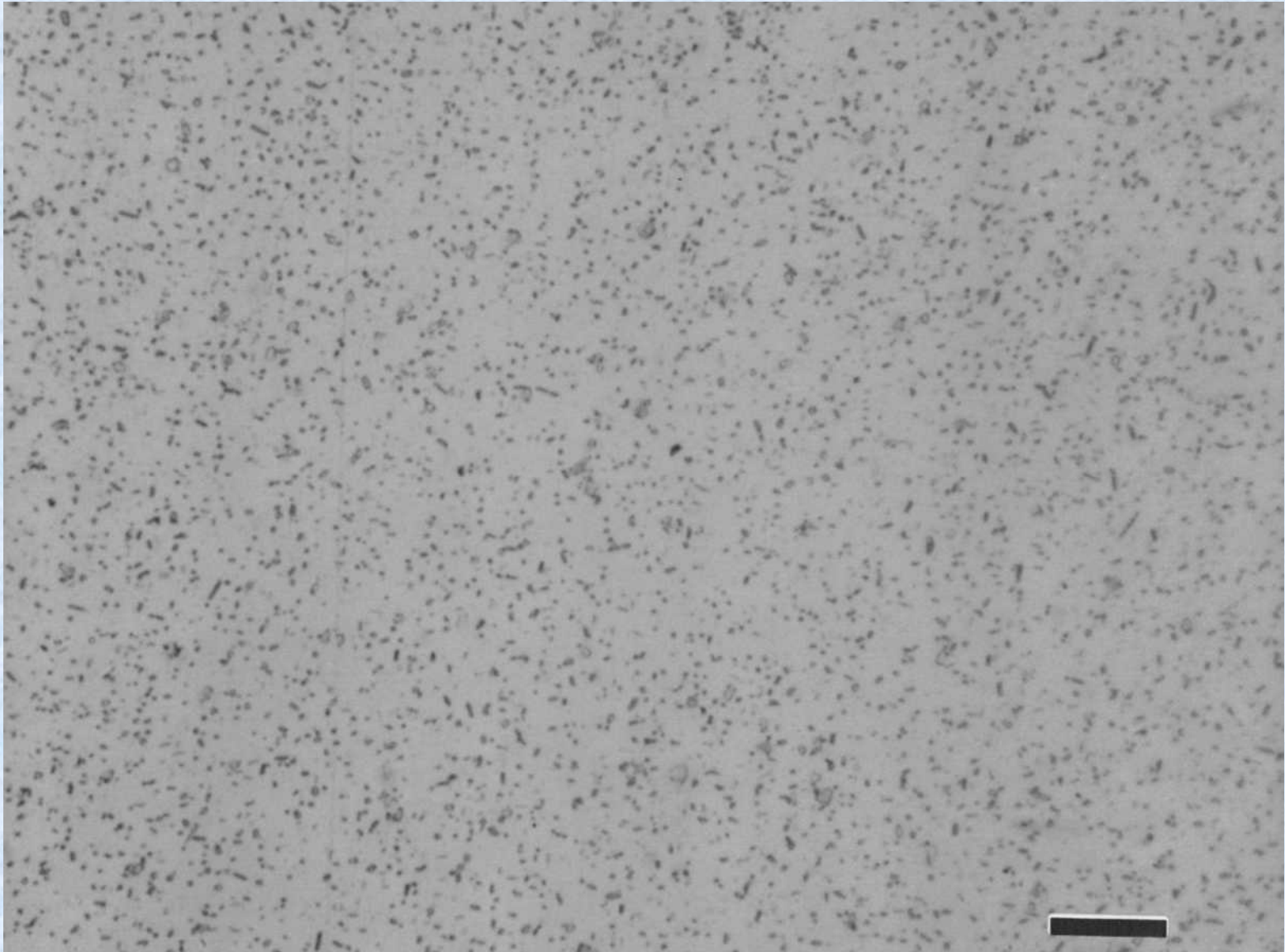
Equiaxed alpha grain structure with criss-cross marks in solution annealed and aged (552 °C, 1025 °F for 1 h, water quench, 316 °C, 600 °F – 1 h, air cool) Al – 4 % Cu etched with Keller's reagent. Bar is 200 µm. Markings are due to fine precipitation in the alpha phase.



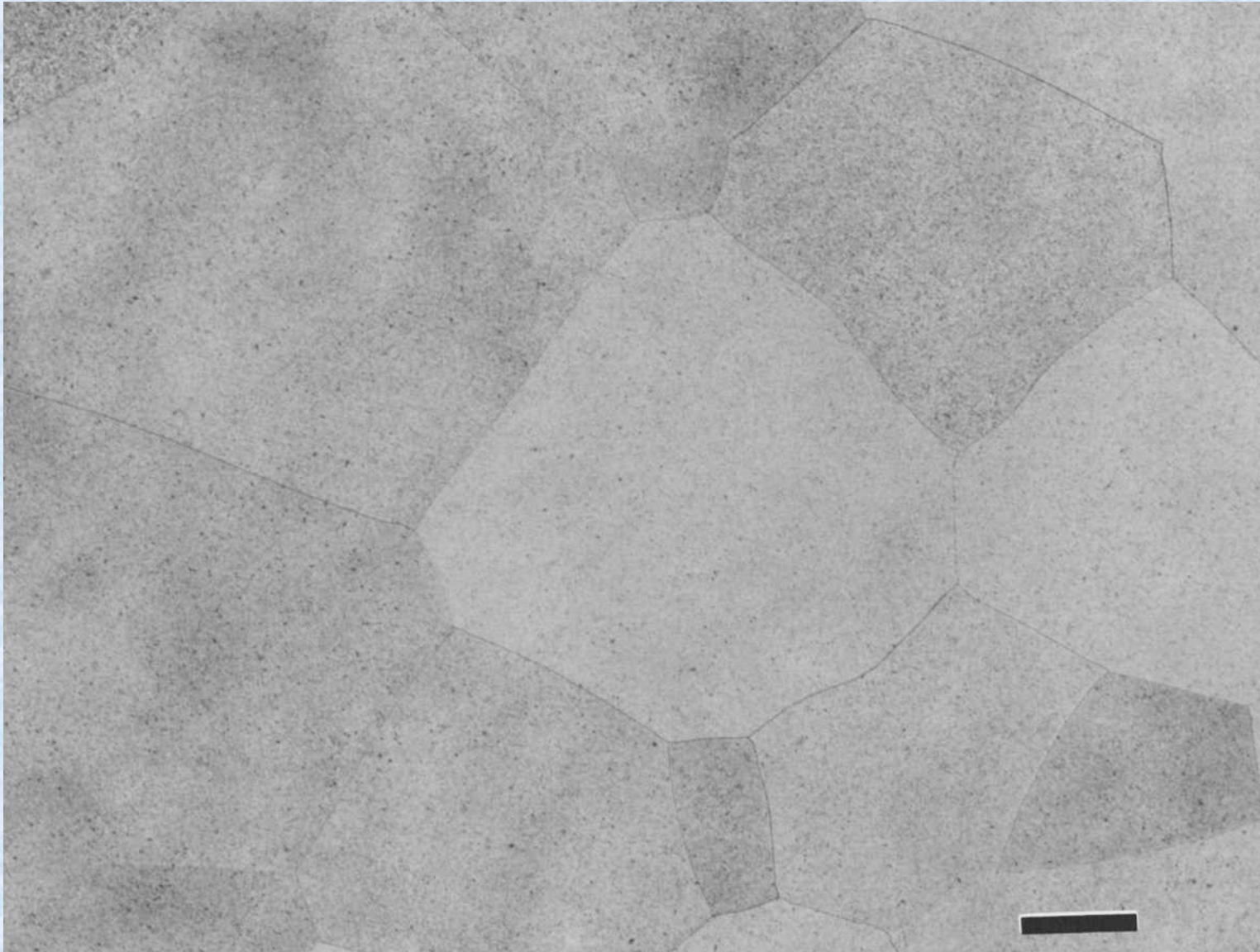
Fine precipitates in solution annealed and aged (552 °C, 1025 °F for 1 h, water quench, 316 °C, 600 °F – 1 h, air cool) Al – 4 % Cu etched with aqueous 0.5% HF. Magnification bar is 10 μ m long.



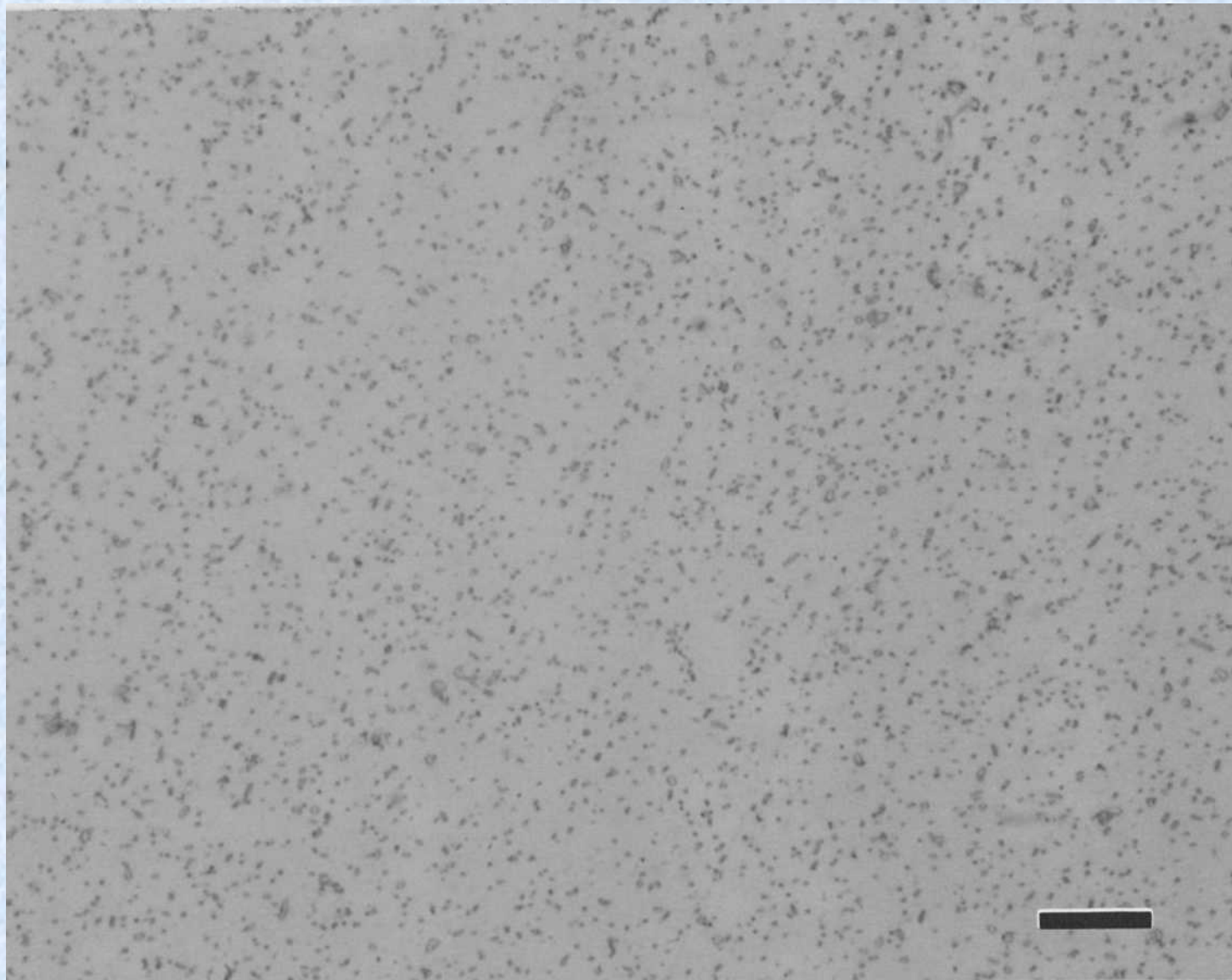
Equiaxed alpha grain structure with criss-cross marks in solution annealed and aged (552 °C, 1025 °F for 1 h, water quench, 371 °C, 700 °F – 1 h, air cool) Al – 4 % Cu etched with Keller's reagent. Bar is 200 μ m. Markings are due to fine precipitation in the alpha phase.



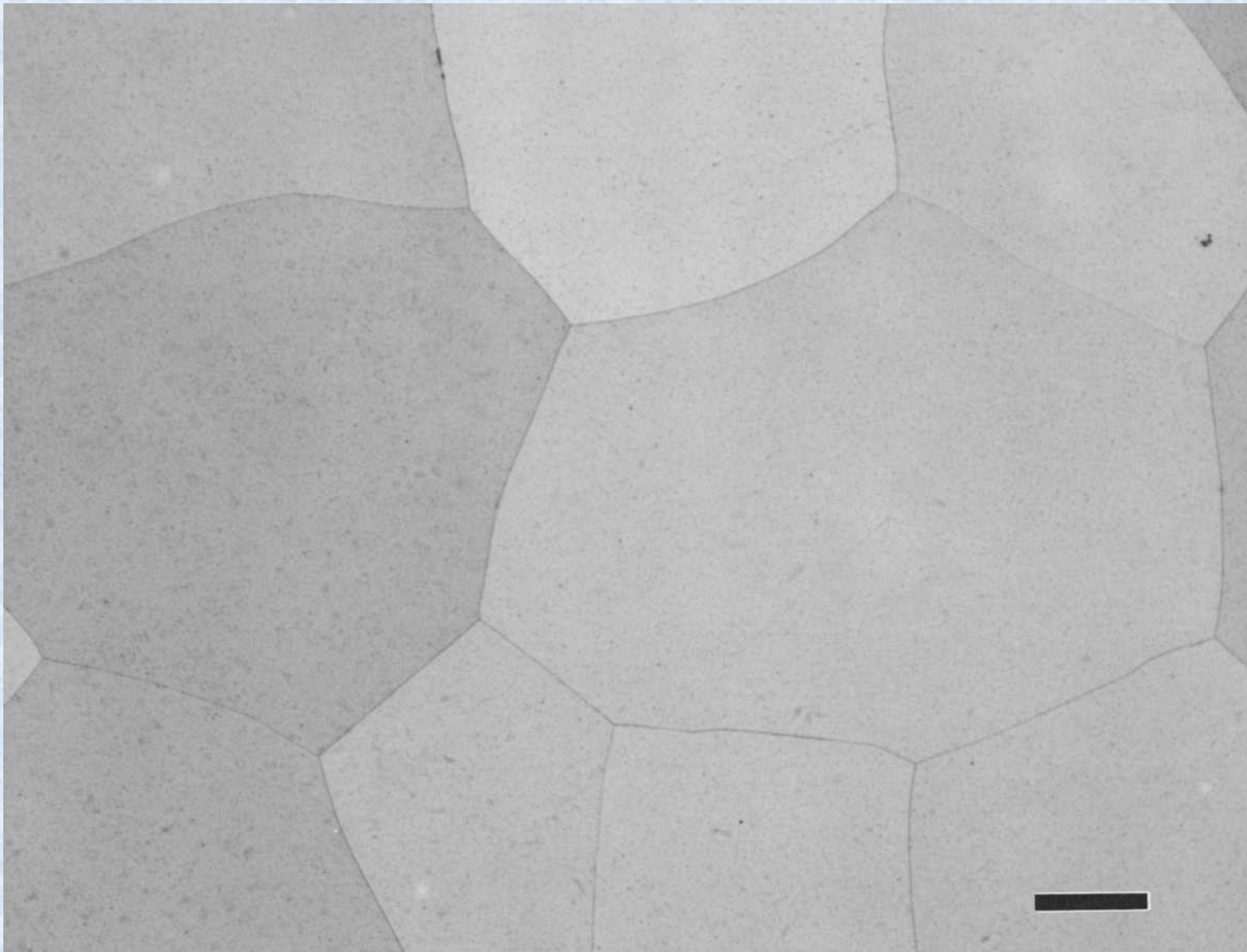
Very fine precipitates in solution annealed and aged (552 °C, 1025 °F for 1 h, water quench, 371 °C, 700 °F – 1 h, air cool) Al – 4 % Cu etched with aqueous 0.5% HF. Magnification bar is 10 μm long.



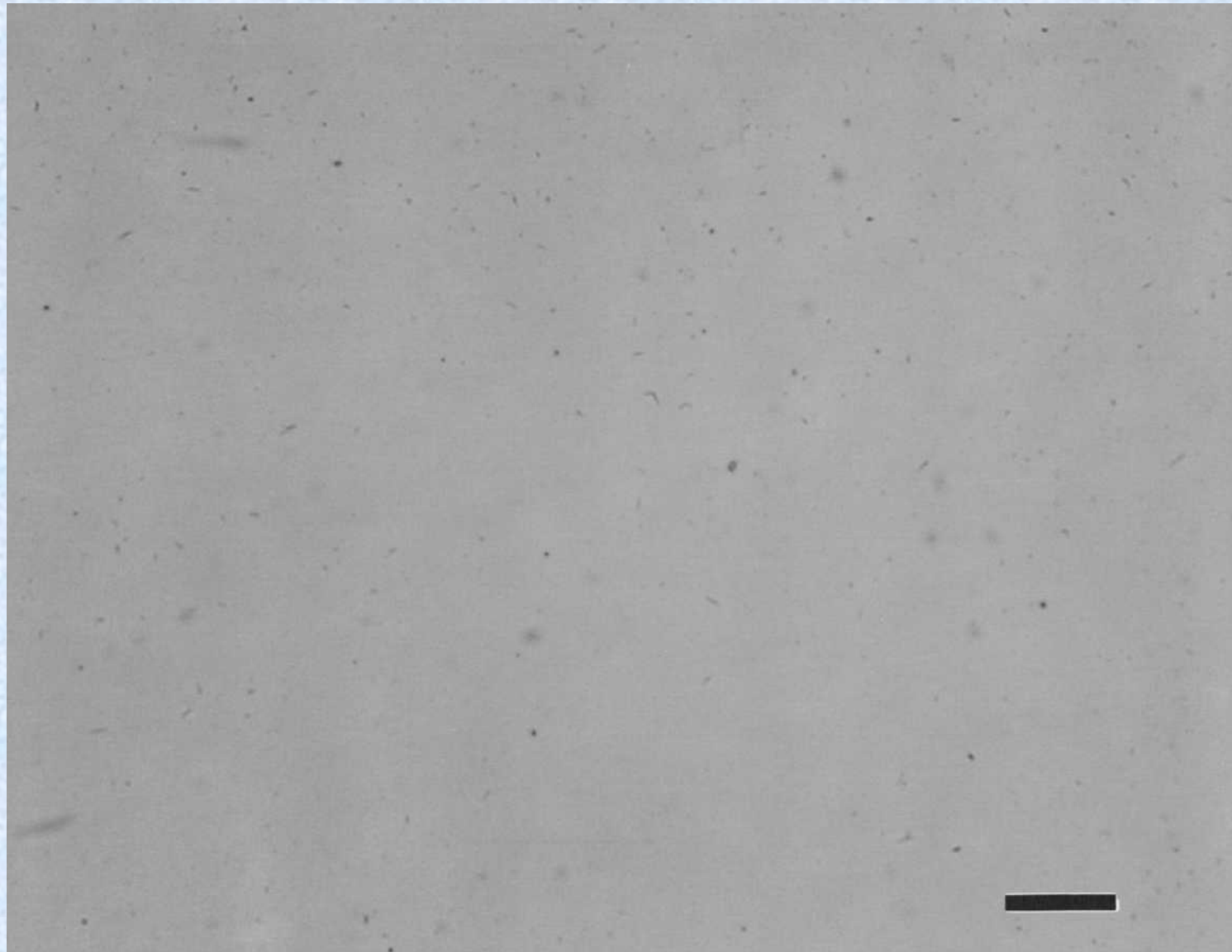
Equiaxed alpha grain structure with criss-cross marks in solution annealed and aged (552 °C, 1025 °F for 1 h, water quench, 427 °C, 800 °F – 1 h, air cool) Al – 4 % Cu etched with Keller's reagent. Bar is 200 μ m. Markings are due to fine precipitation in the alpha phase.



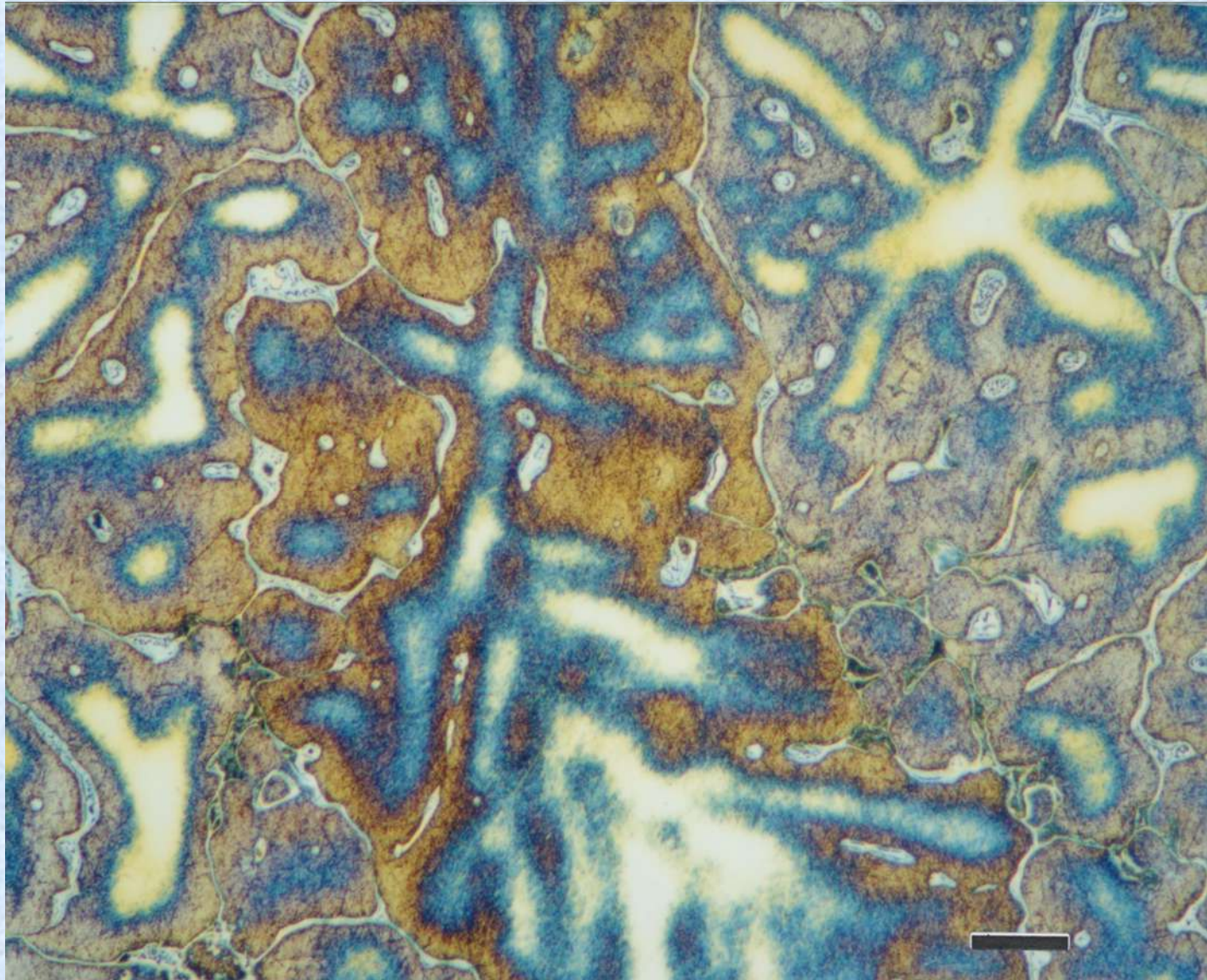
Fine precipitates in solution annealed and aged (552 °C, 1025 °F for 1 h, water quench, 427 °C, 800 °F – 1 h, air cool) Al – 4 % Cu etched with aqueous 0.5% HF. Magnification bar is 10 μ m long.



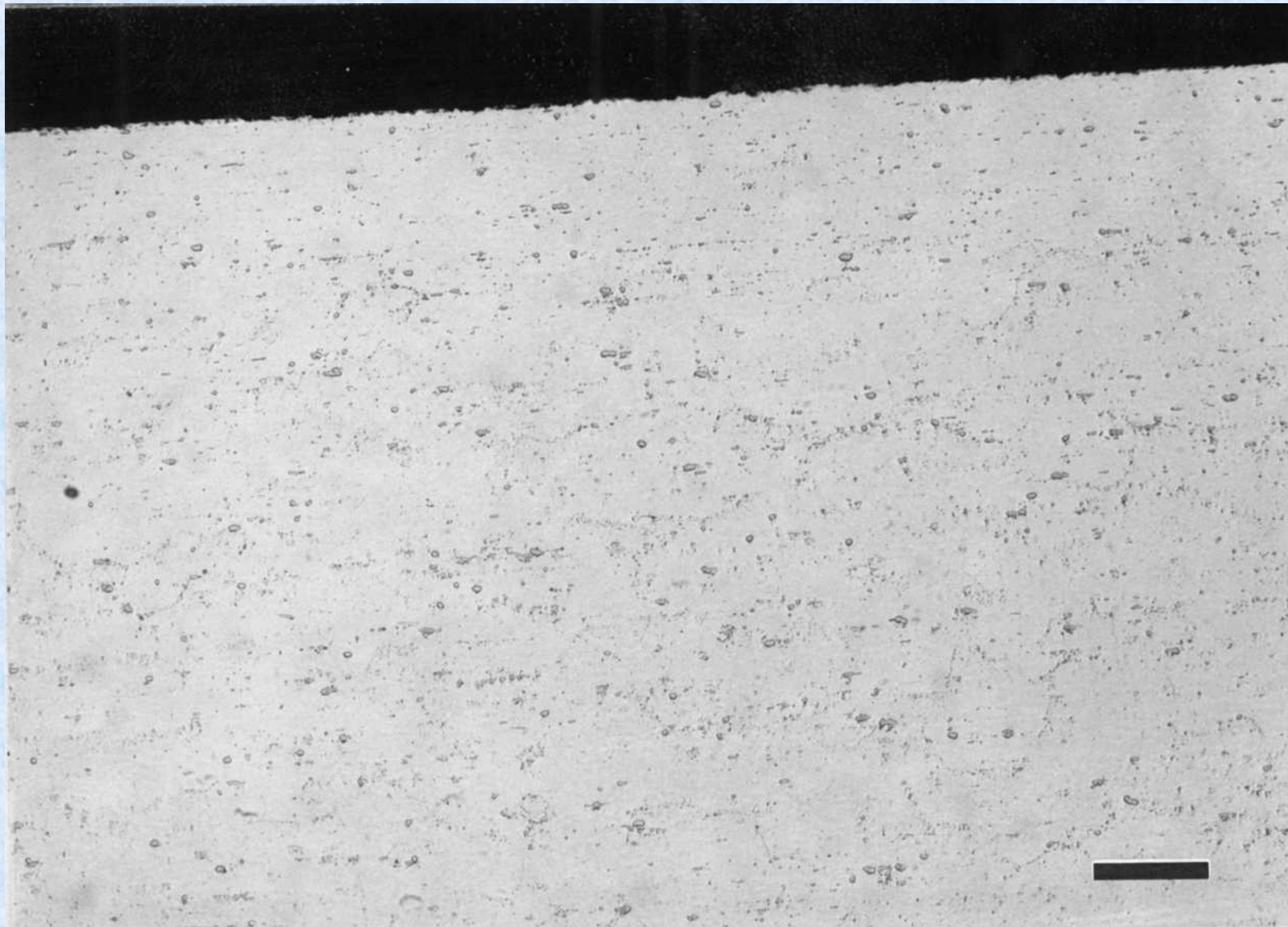
Equiaxed alpha grain structure in solution annealed and aged (552 °C, 1025 °F for 1 h, water quench, 538 °C, 1000 °F – 1 h, air cool) Al – 4 % Cu etched with Keller’s reagent. Magnification bar is 200 μm long. Criss-cross markings are no longer present because the high aging temperature has dissolved nearly all of the fine precipitates in the alpha phase. Compare with the solution annealed image at the same magnification.



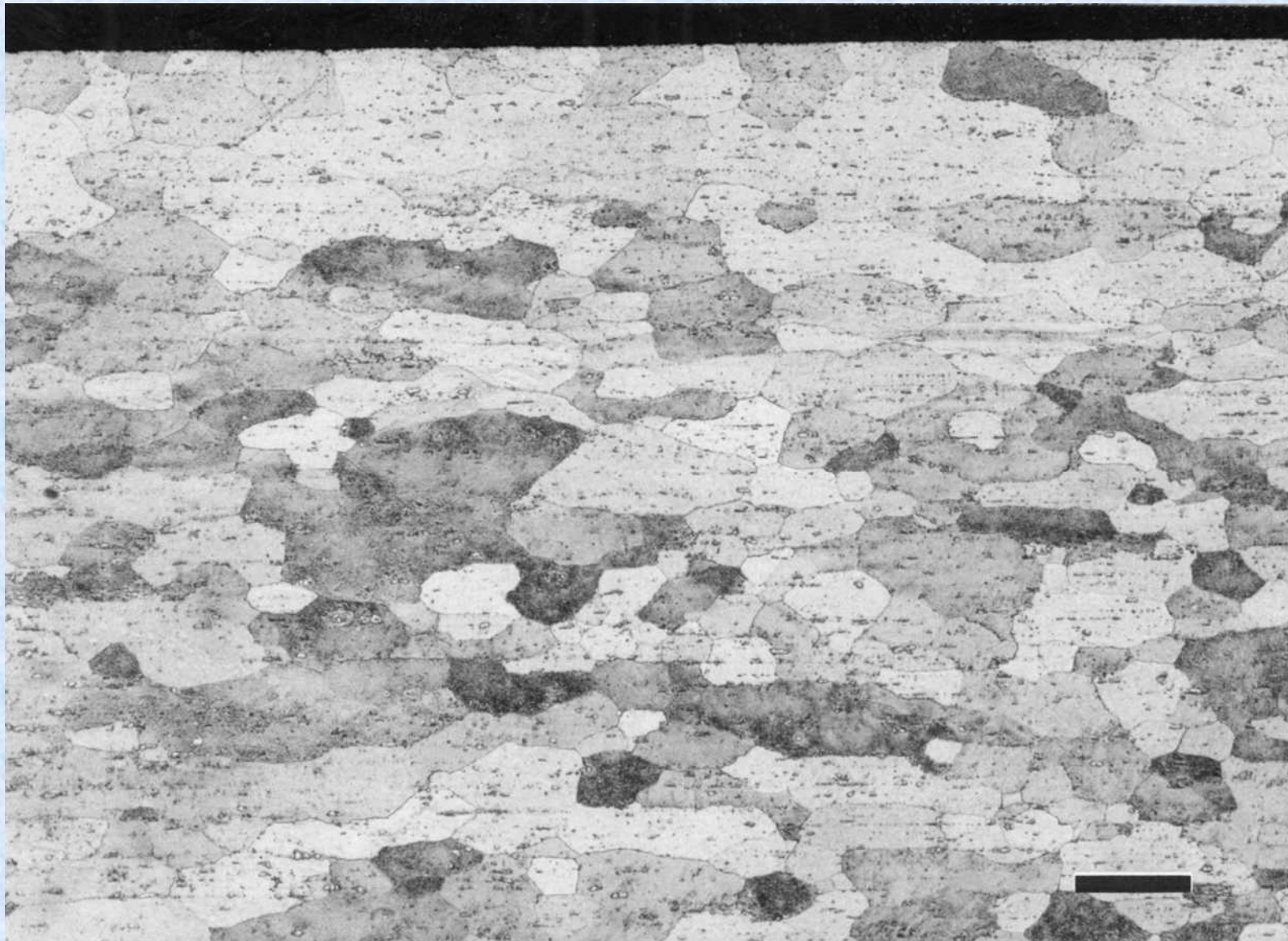
Near absence of precipitates in solution annealed and aged (552 °C, 1025 °F for 1 h, water quench, 538 °C, 1000 °F – 1 h, air cool) Al – 4 % Cu etched with aqueous 0.5% HF. Magnification bar is 10 μ m long. The high aging temperature has dissolved nearly all of the fine precipitates in the alpha phase. Compare with the solution annealed image at the same magnification.



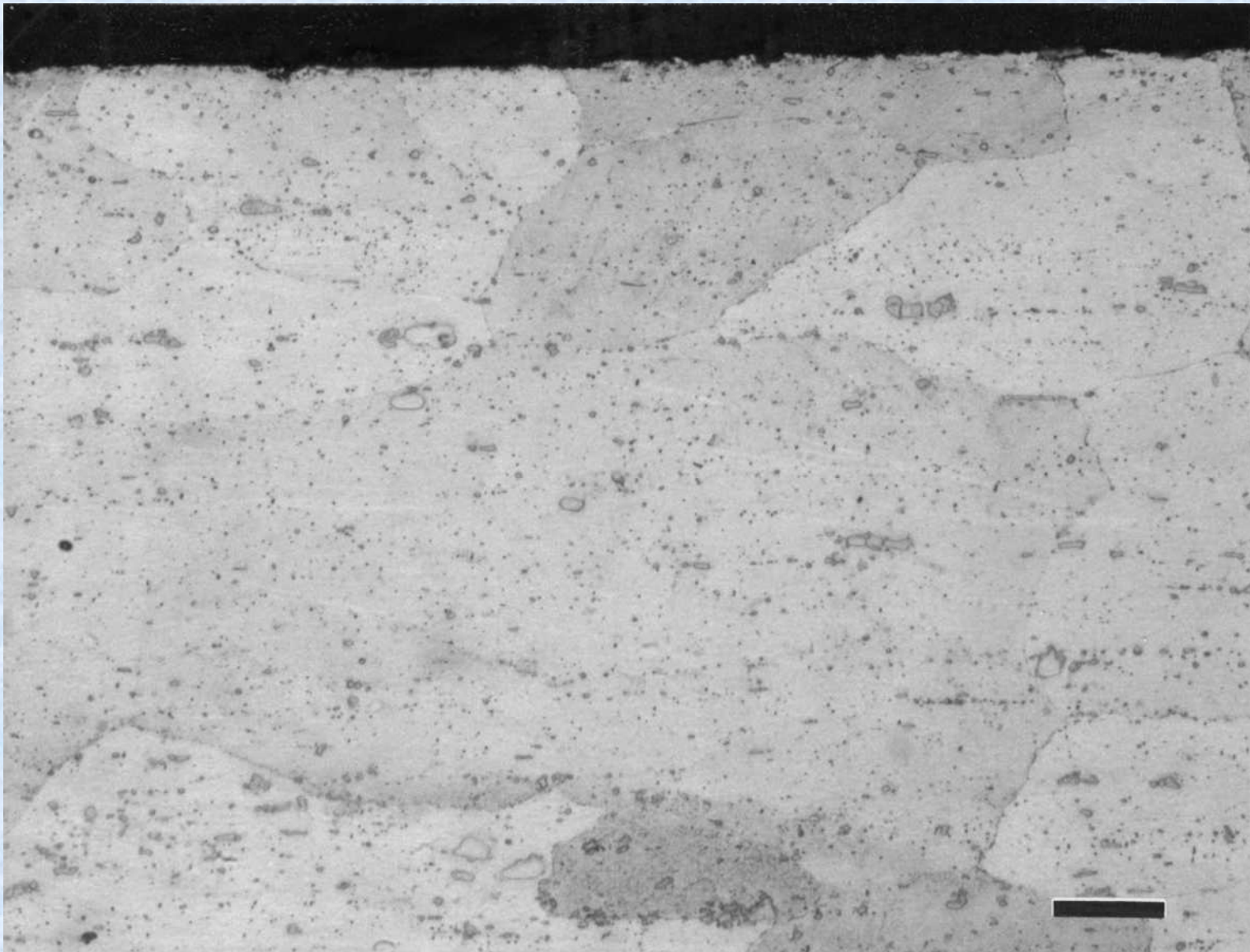
As-cast Al – 4.5% Cu tint etched with Weck’s reagent. Magnification bar is 50 μm long. Viewed with crossed polarized light plus sensitive tint. Microstructure reveals “coring” segregation within the dendrites and intermetallics between the dendrites.



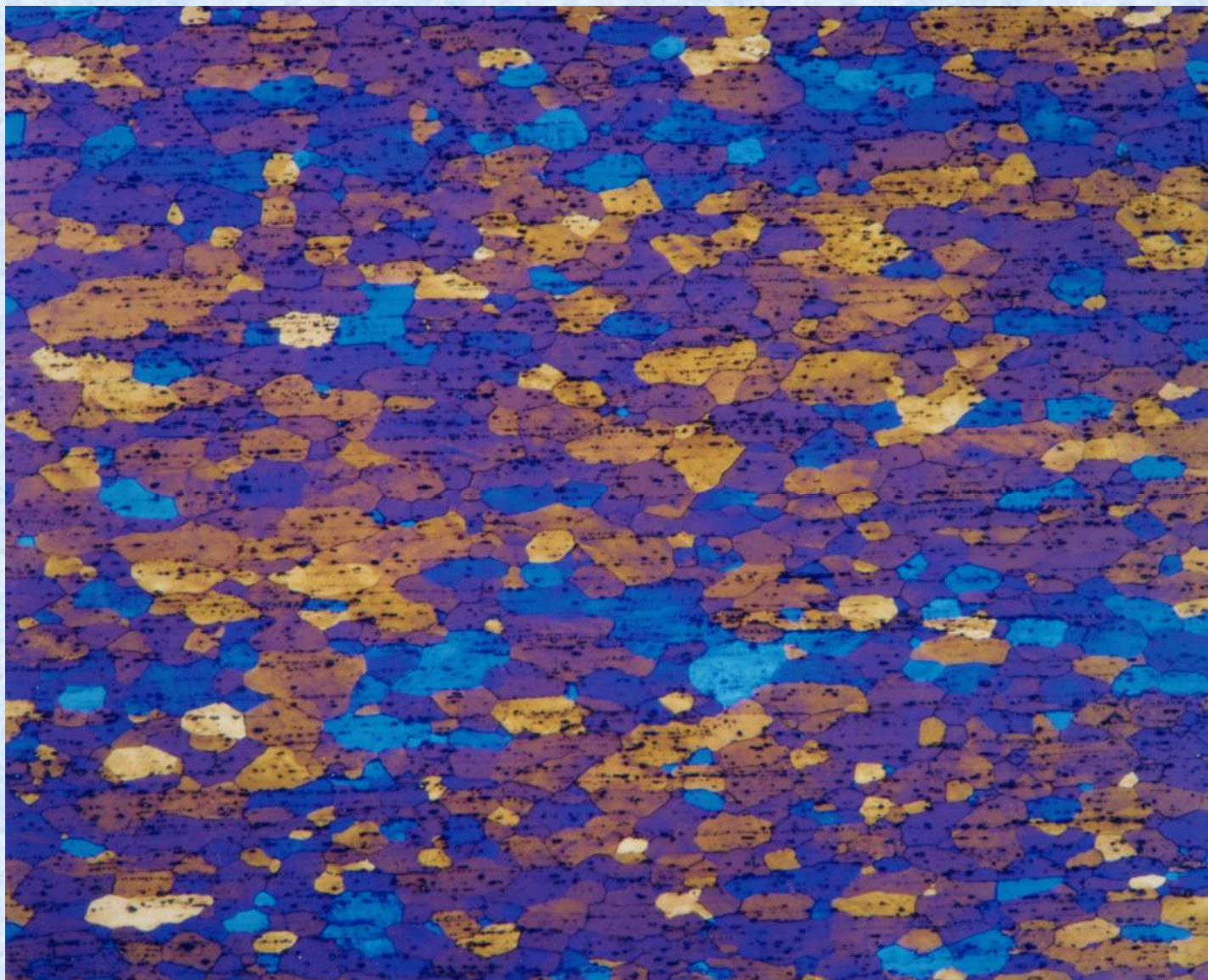
**Wrought 2011-T3 aluminum (Al – 5.5% Cu), as polished, showing the surface and intermetallic particles.
Magnification bar is 100 μm long.**



Wrought 2011-T3 aluminum (Al – 5.5% Cu), etched with Keller’s reagent, showing the grain structure and intermetallic particles at the bar surface. Note that the grains are elongated somewhat in processing. Magnification bar is 100 μm long.



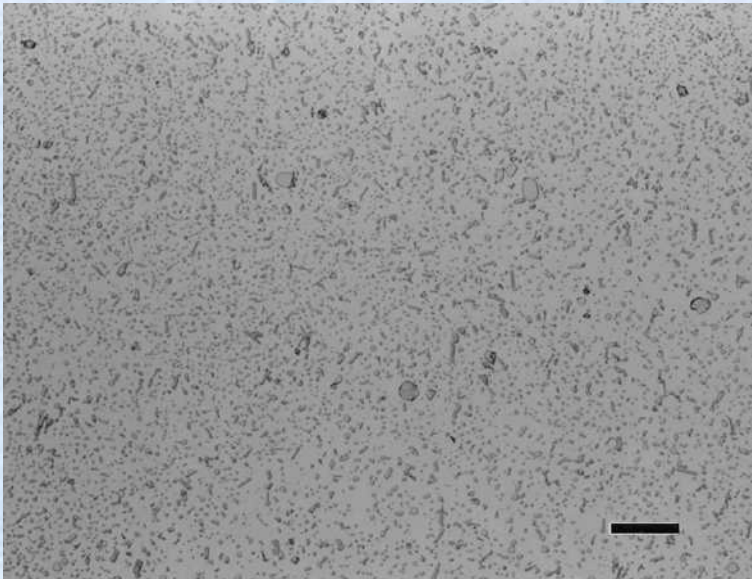
Wrought 2011-T3 aluminum (Al – 5.5% Cu), after etching with Keller's reagent, showing the surface, grain structure and intermetallic particles (higher magnification view of previously shown image). Magnification bar is 20 μm long.



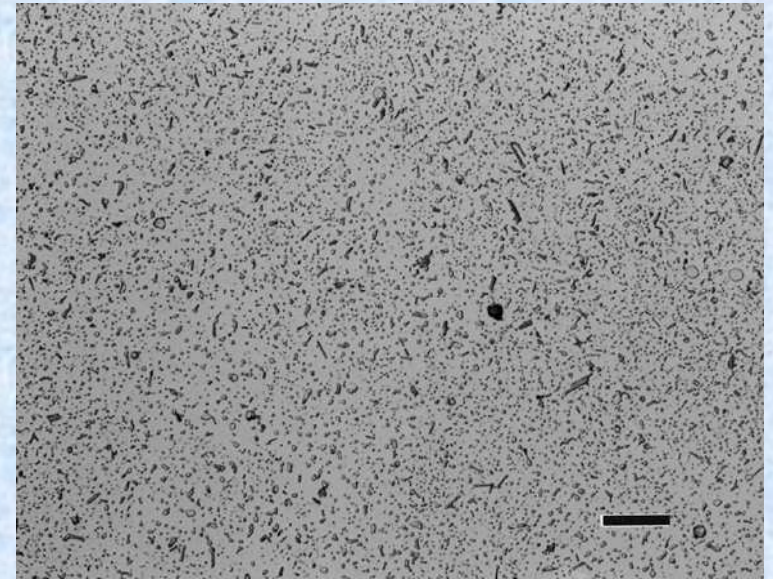
Wrought 2011-T3 aluminum (Al – 5.5% Cu), anodized with Barker's reagent (20 V dc, 2 min.), showing the elongated grain structure and intermetallic particles. Original at 50X. Viewed with crossed polarized light plus sensitive tint.

2011-0

Keller's



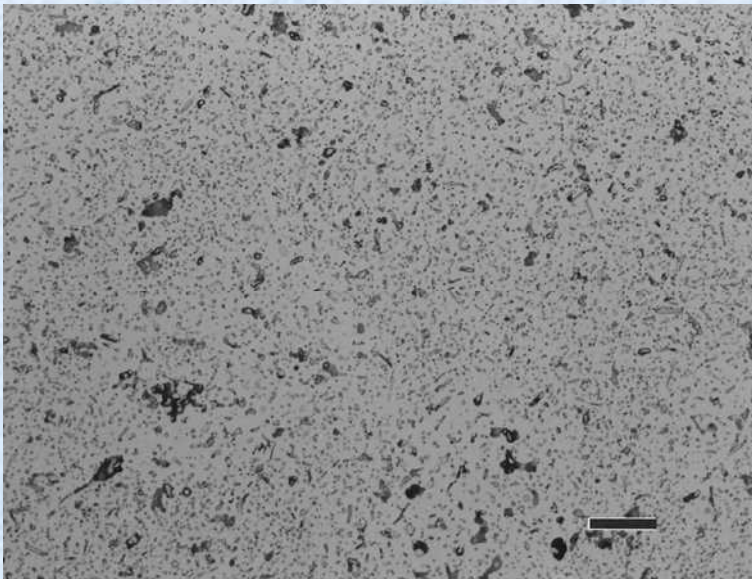
NaF-NaOH



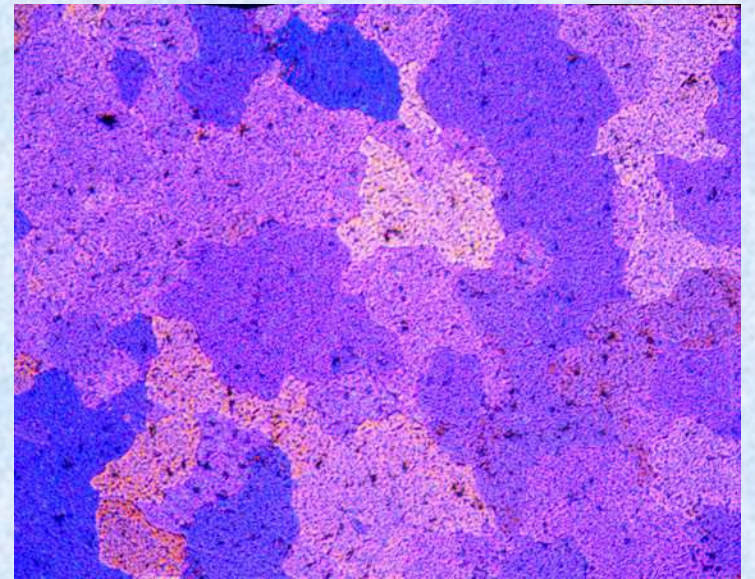
**B&W –
Bars are
20- μ m long
500X**

**Color is
200X**

Graff-Sargent

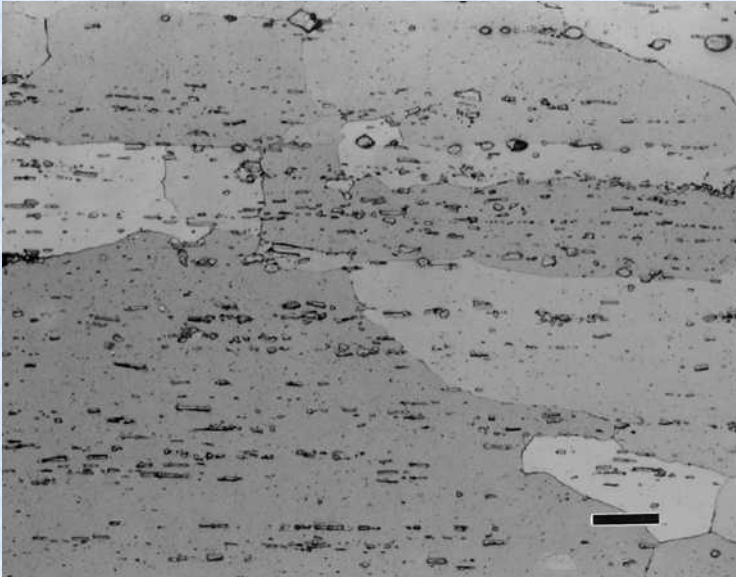


Weck's

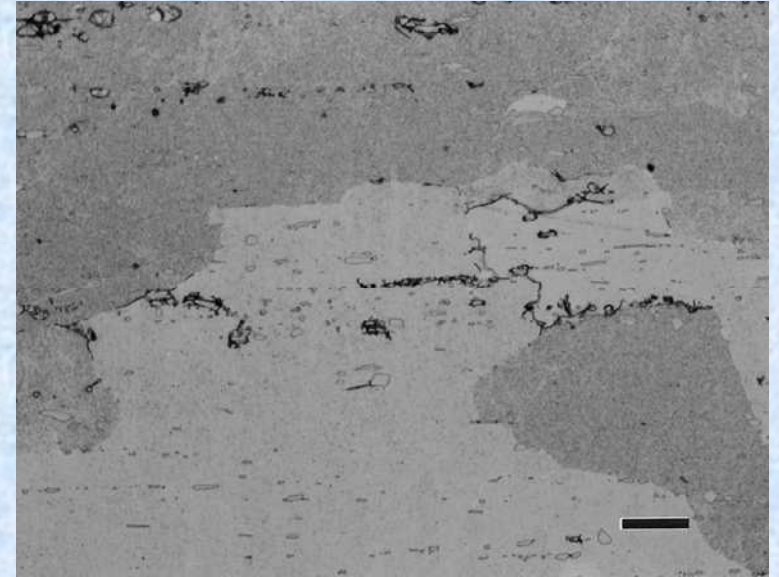


2011-T3

Keller's



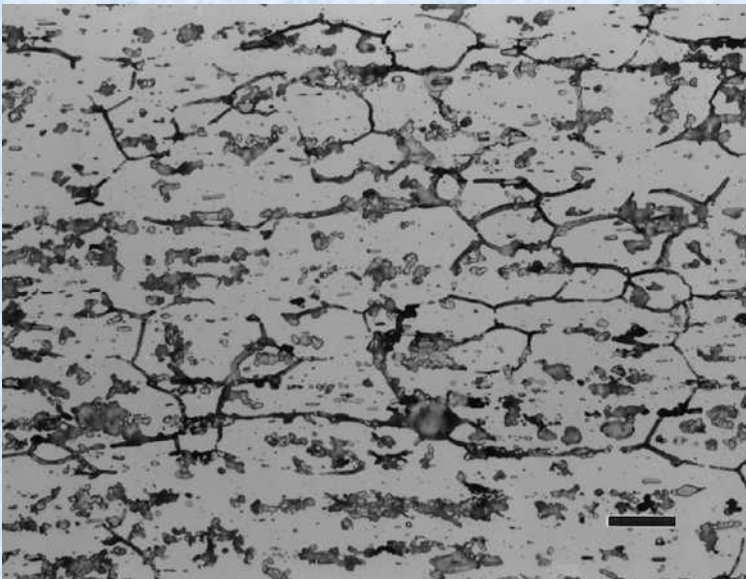
NaF-NaOH



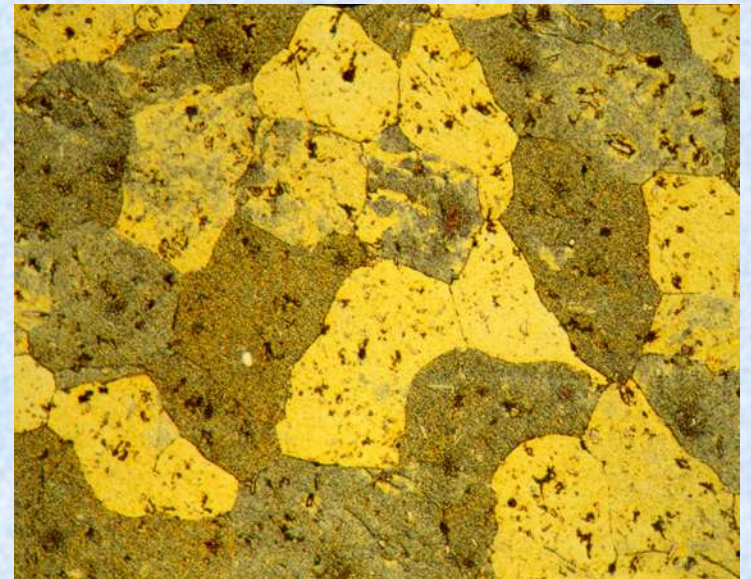
B&W –
Bars are
20- μ m long
500X

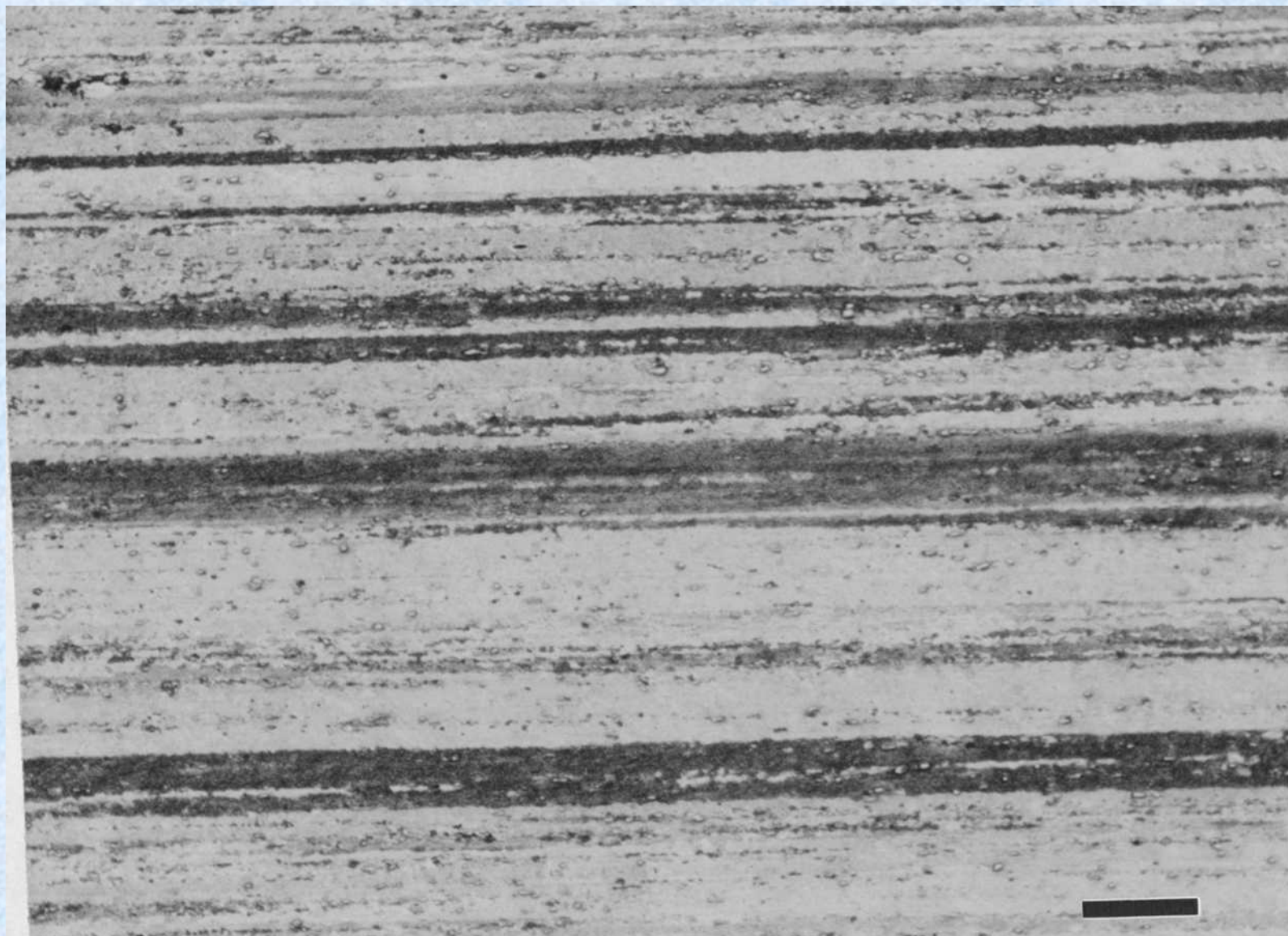
Color is
500X

Graff-Sargent

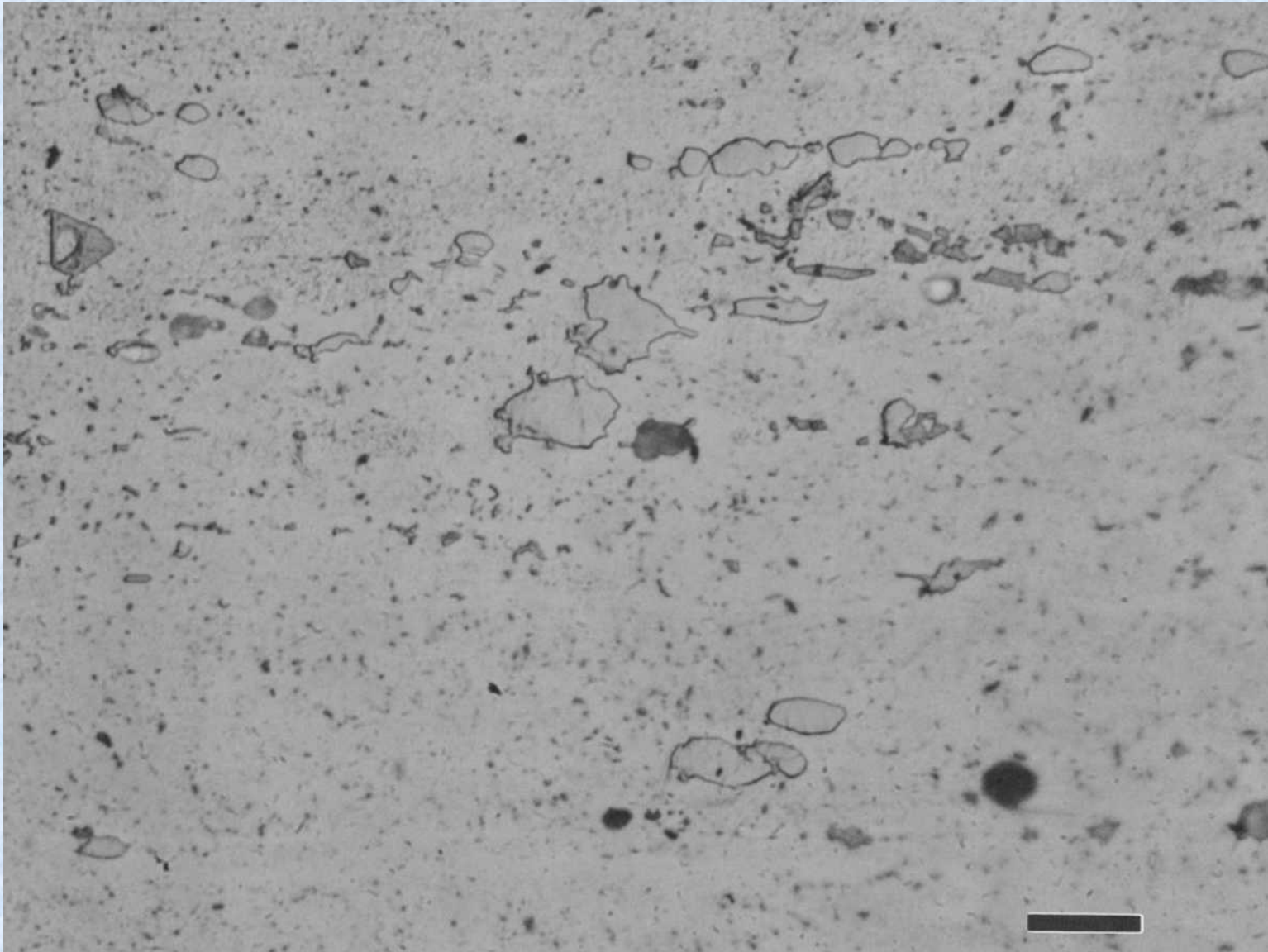


Weck's

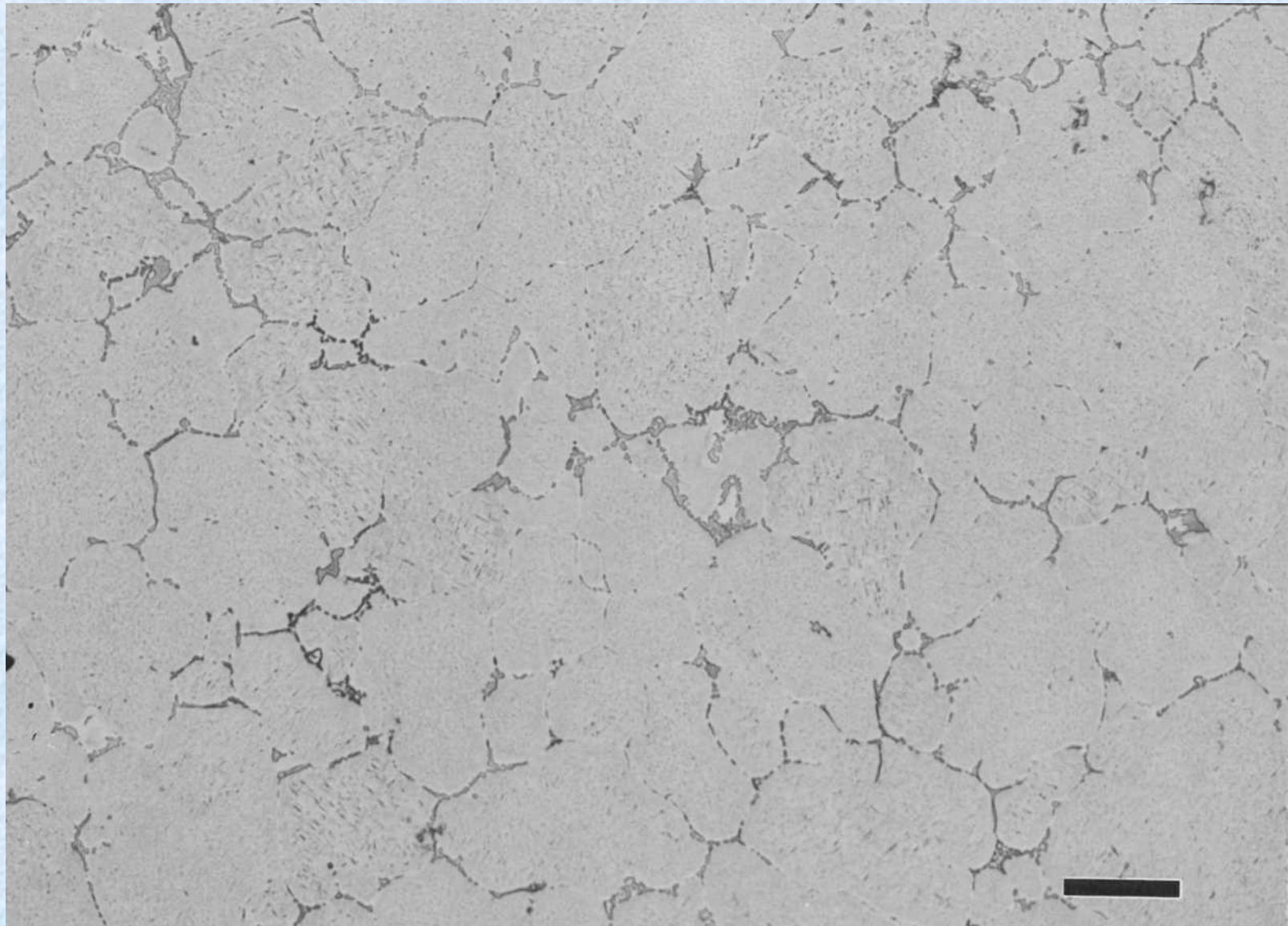




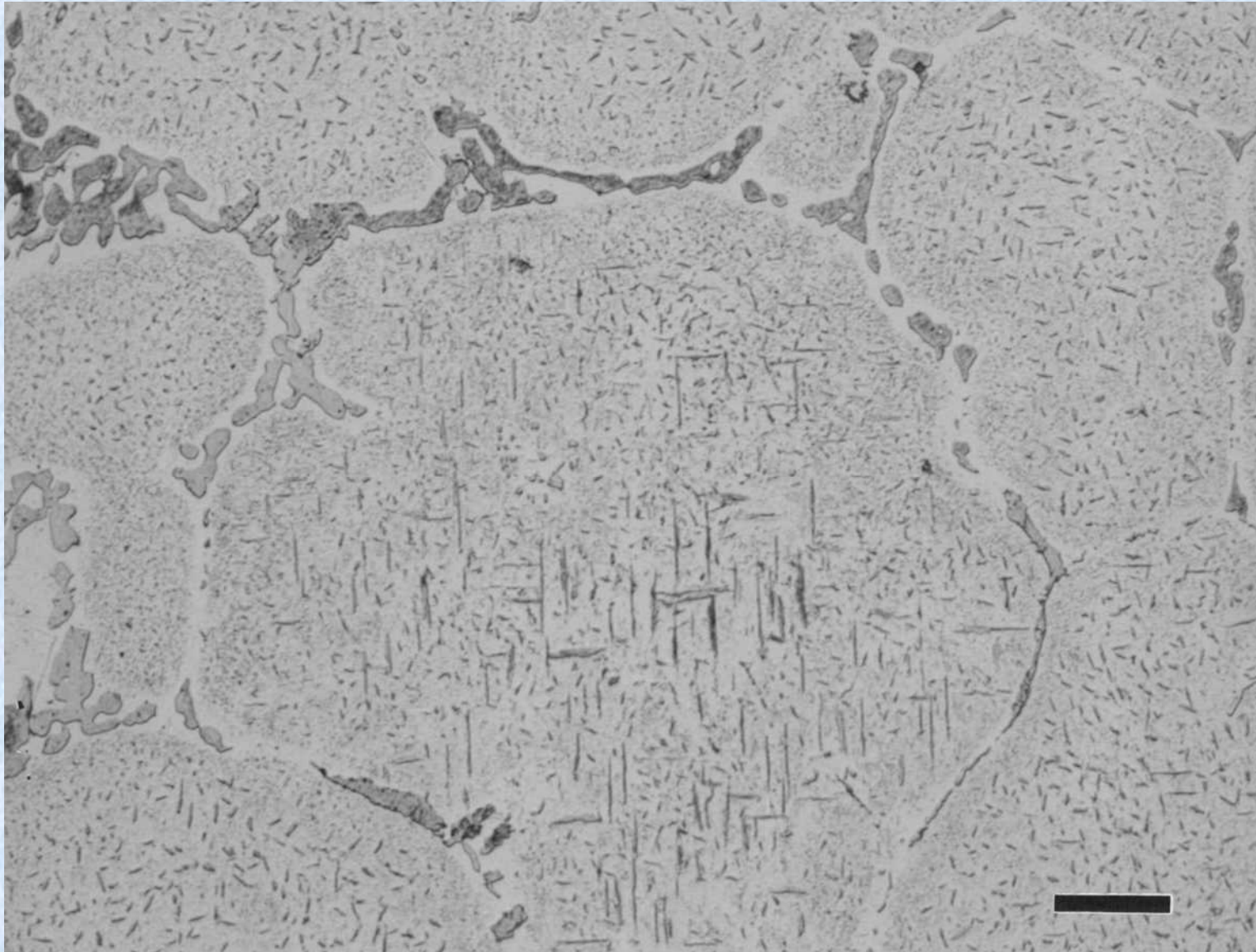
Extruded Al – 4.6% Cu – 0.7% Si – 0.3% Fe – 0.7% Mg – 0.7% Mn with highly elongated alpha grains and intermetallics. Etched with Keller's reagent. Magnification bar is 100 μm long.



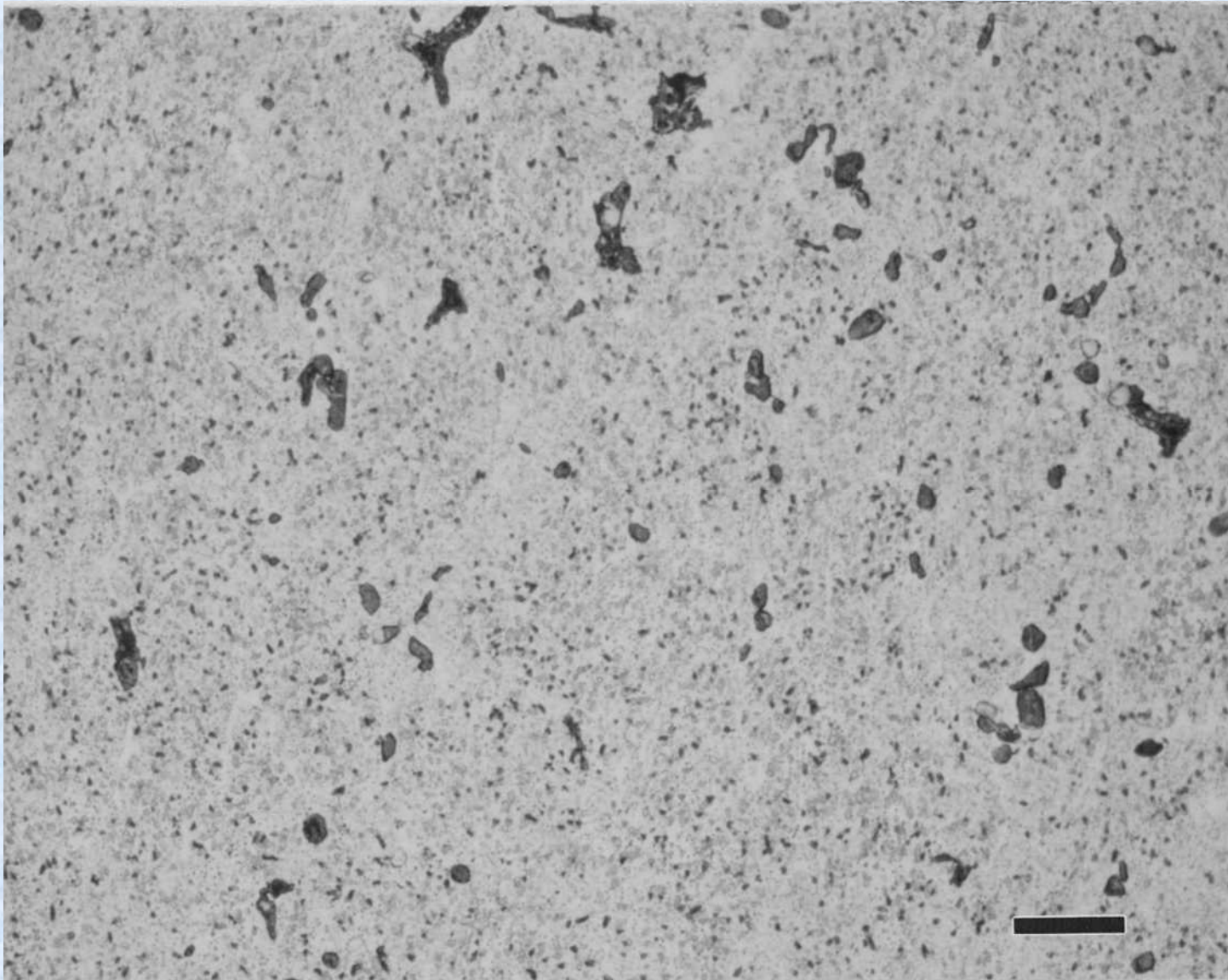
Extruded Al – 4.6% Cu – 0.7% Si – 0.3% Fe – 0.7% Mg – 0.7% Mn showing the intermetallics, CuAl_2 , $(\text{FeMn})\text{Al}_6$ and Mg_2Si . Etched with aqueous 0.5% HF. Magnification bar is 10 μm long.



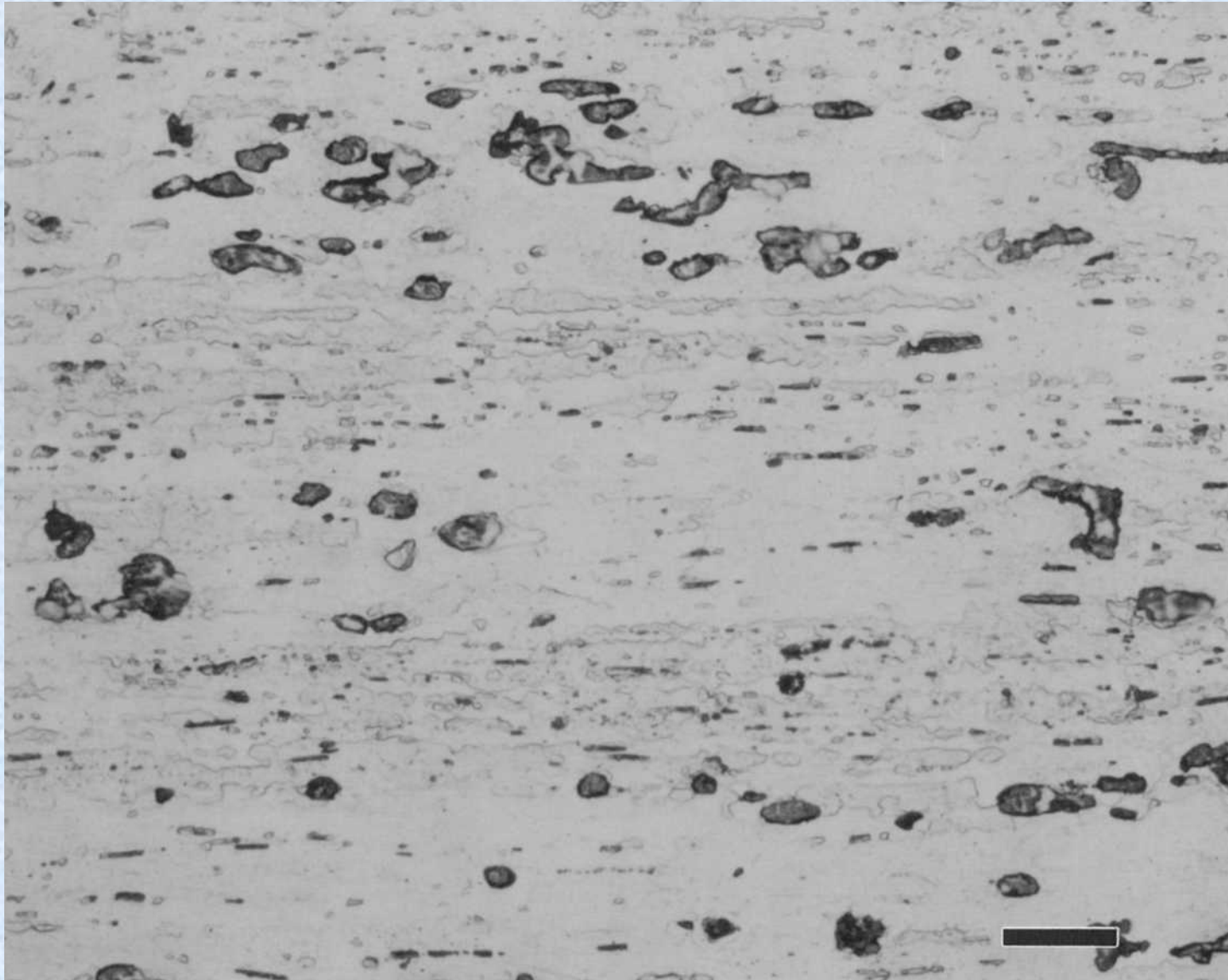
As-cast 2024 aluminum (Al – 4.4% Cu – 1.5% Mg – 0.6% Mn) that was not homogenized revealing coarse primary intermetallics in the interdendritic locations. Magnification bar is 100 μm long. Etched with aqueous 0.5% HF.



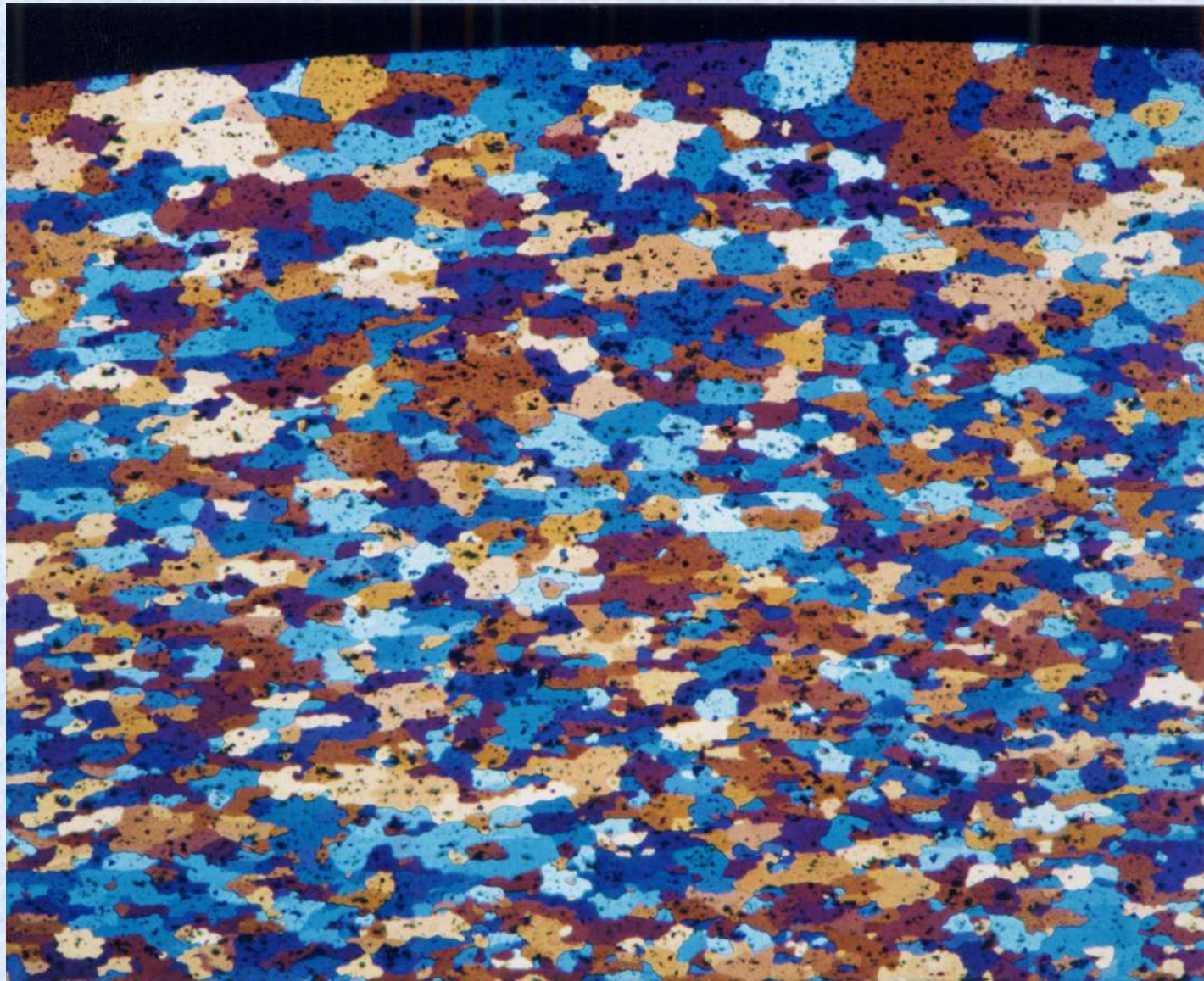
As-cast 2024 aluminum (Al – 4.4% Cu – 1.5% Mg – 0.6% Mn) that was not homogenized revealing coarse primary intermetallics in the interdendritic locations and coarse precipitates within the dendrites formed during subsequent slow cooling of the ingot. Magnification bar is 20 μ m long. Etched with aqueous 0.5% HF.



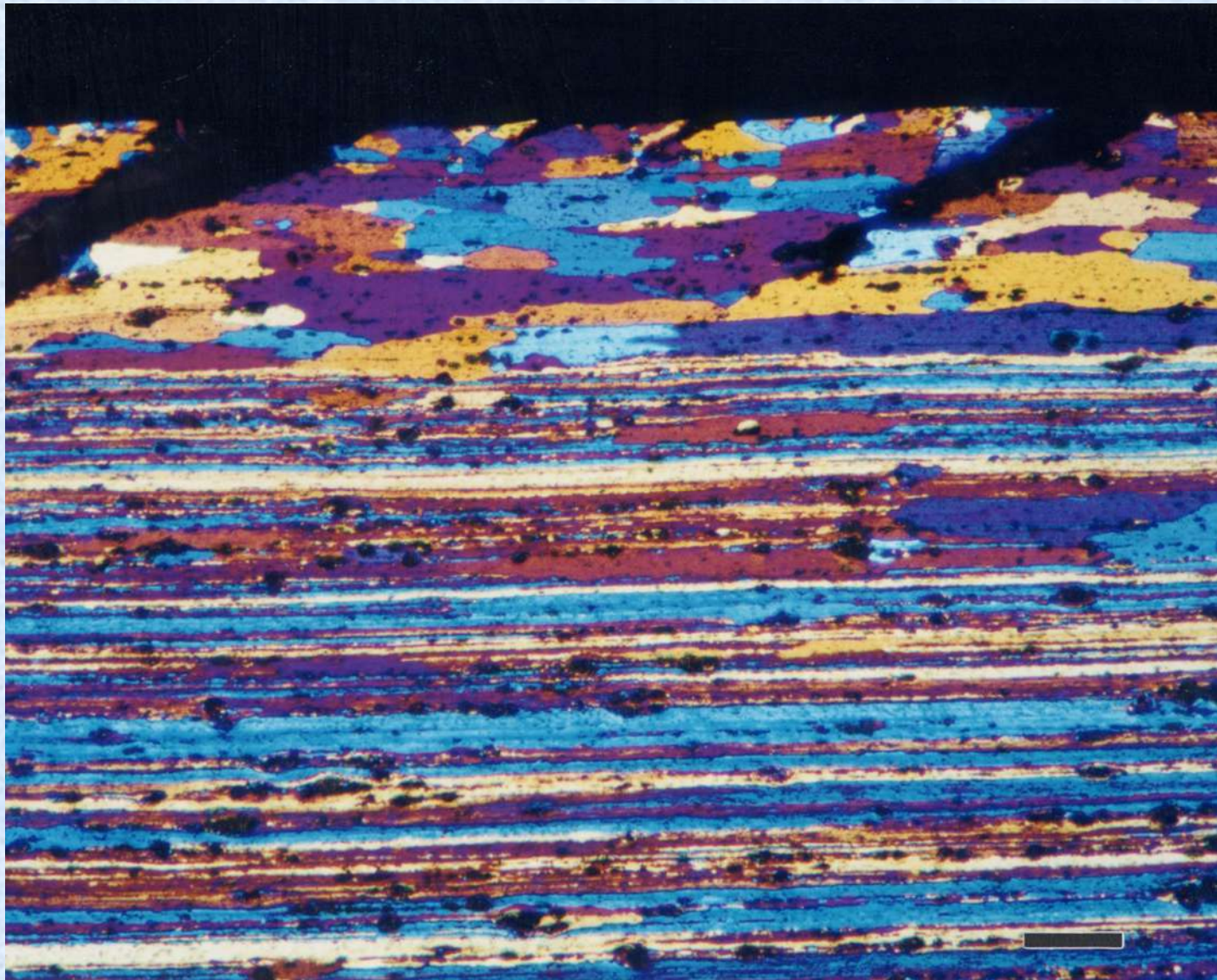
Wrought 2024-F aluminum (Al – 4.4% Cu – 1.5% Mg – 0.6% Mn) bar (28.5 mm diameter) showing the intermetallics. Magnification bar is 20 μm long. Etched with Keller's reagent. Transverse plane.



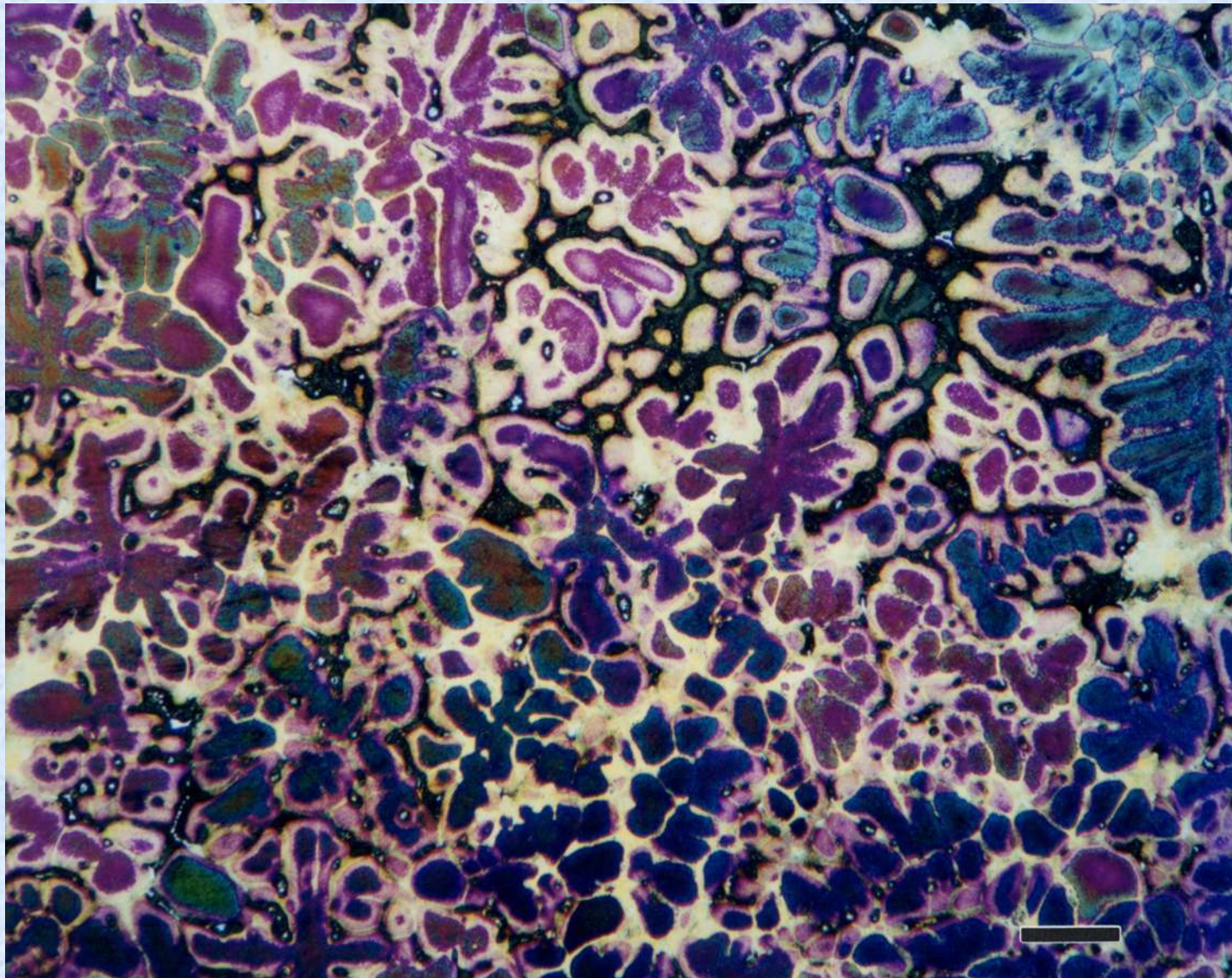
Wrought 2024-F aluminum (Al – 4.4% Cu – 1.5% Mg – 0.6% Mn) bar (28.5 mm diam.) showing the intermetallics. Magnification bar is 20 μ m long. Etched with Keller's reagent. Longitudinal plane.



Wrought 2024-F aluminum (Al – 4.4% Cu – 1.5% Mg – 0.6% Mn) bar (28.5 mm diam.) showing the grain structure and intermetallics. Magnification bar is 200 μm long. Anodized with Barker's reagent (30 V dc, 2 min.). Transverse plane.



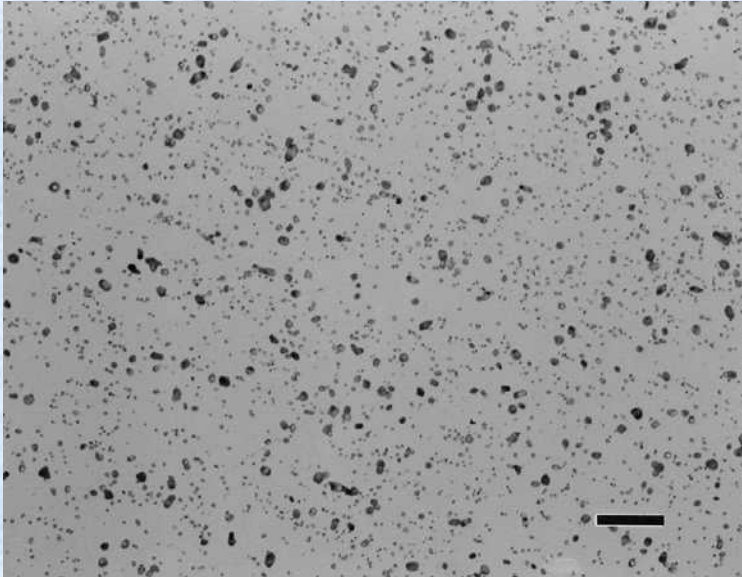
Extruded 2024 aluminum (Al – 4.4% Cu – 1.5% Mg – 0.6% Mn) bar showing a coarse grained surface layer with tears, highly elongated grain structure in the interior of the extrusion and intermetallics. Magnification bar is 100 μ m long. Anodized with Barker's reagent (30 V dc, 2 min.). Longitudinal plane.



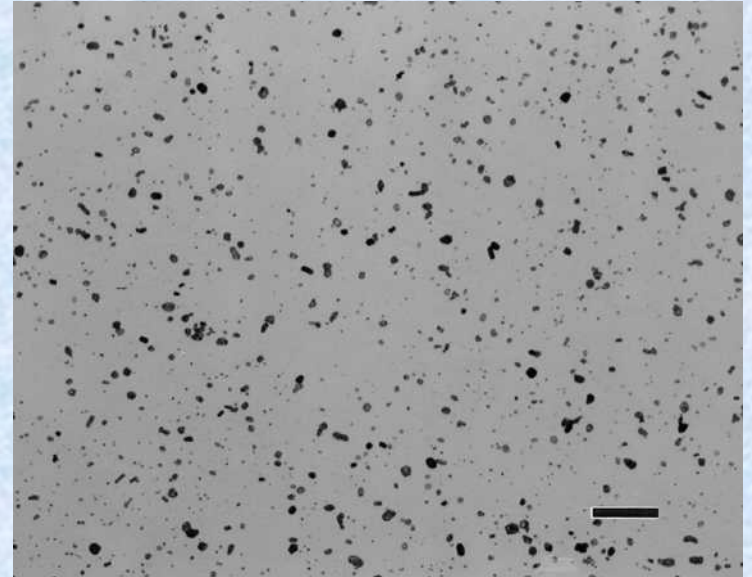
As-cast 3003 aluminum (Al – 1.2% Mn – 0.15% Cu) tint etched with Weck's reagent and viewed with crossed polars and sensitive tint. Magnification bar is 200 μm long. Shows dendritic segregation ("coring").

3003

Keller's



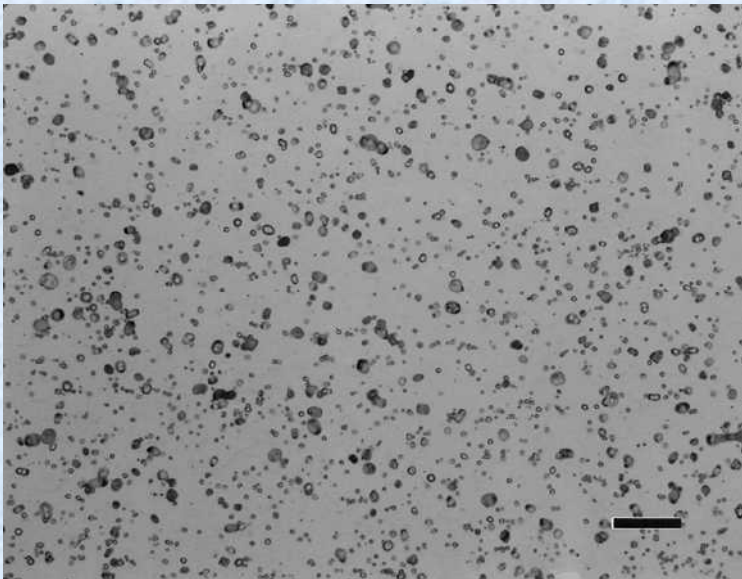
NaF-NaOH



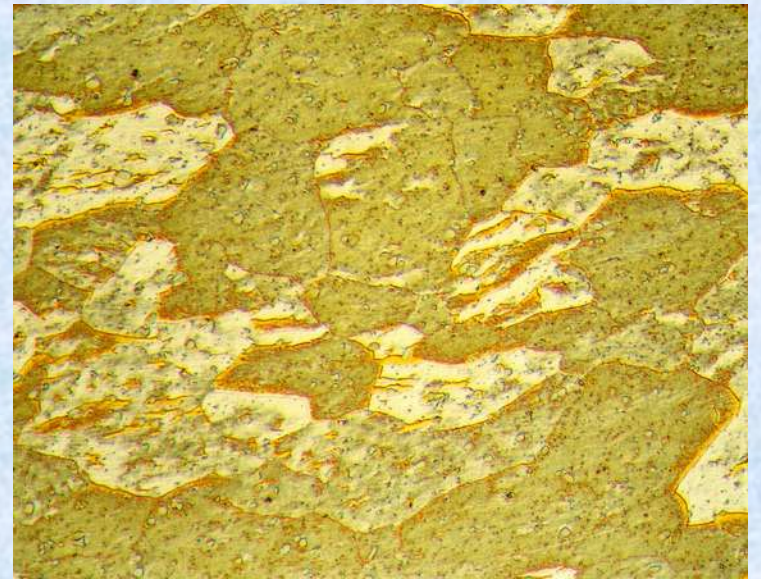
**B&W –
Bars are
20- μ m long
500X**

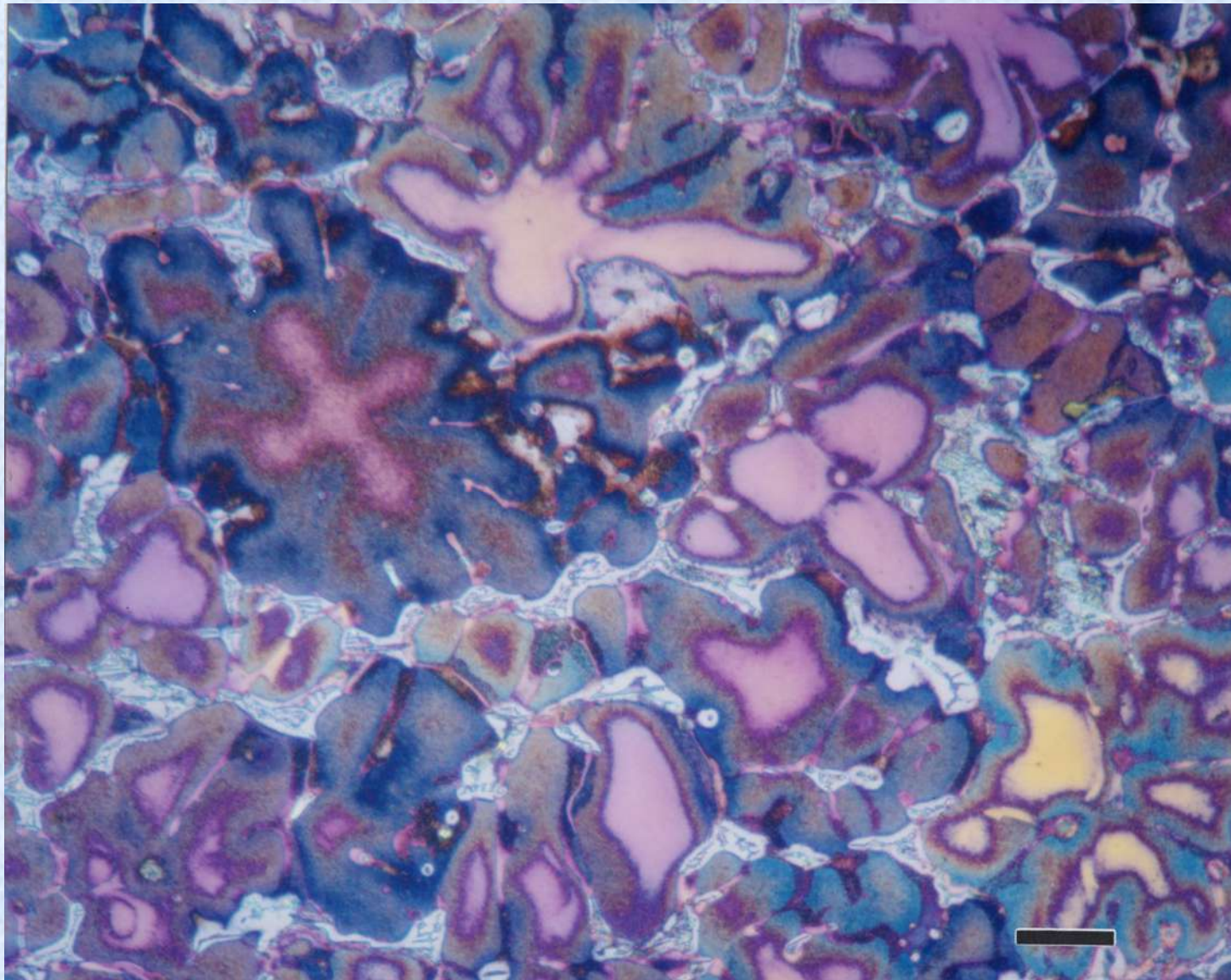
**Color is
500X**

Graff-Sargent

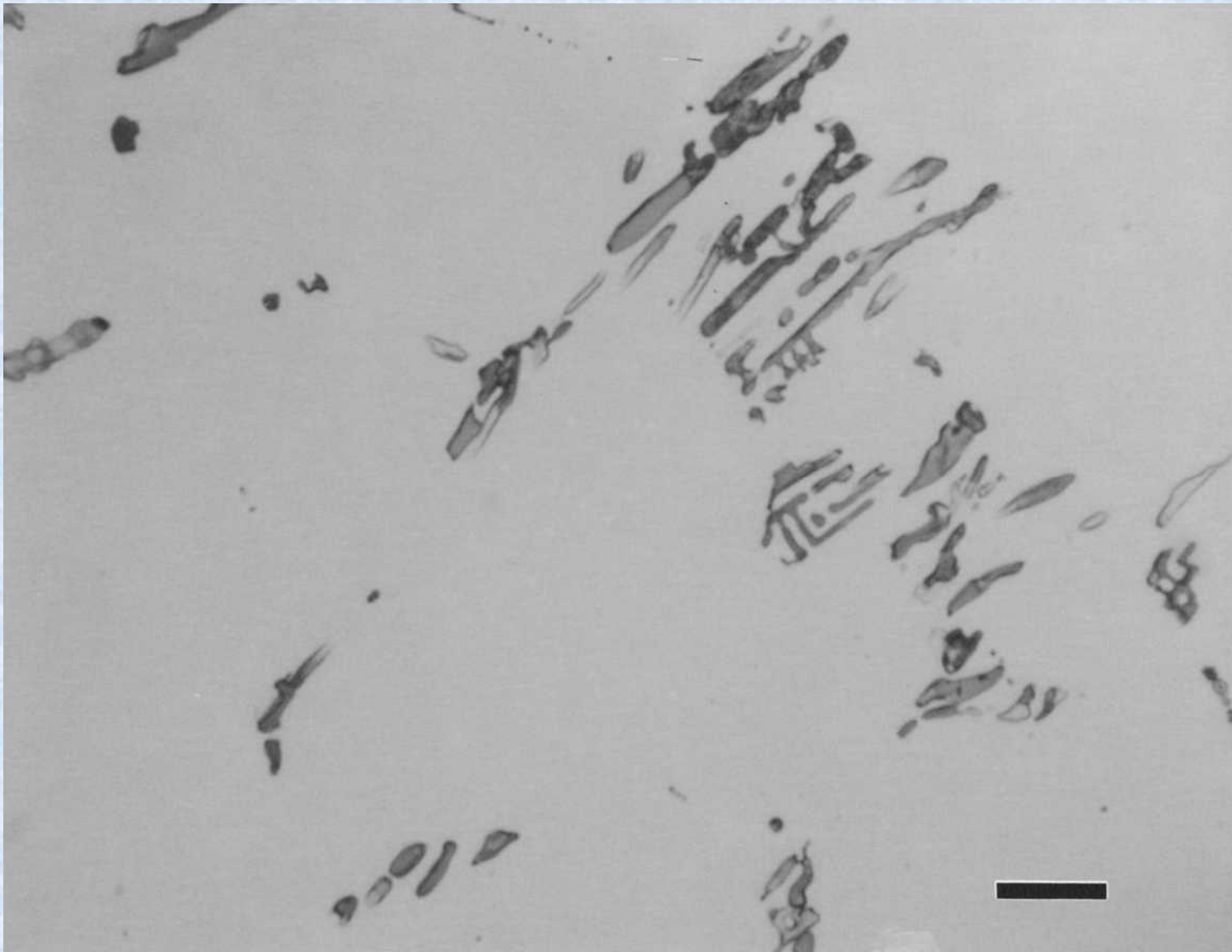


Weck's



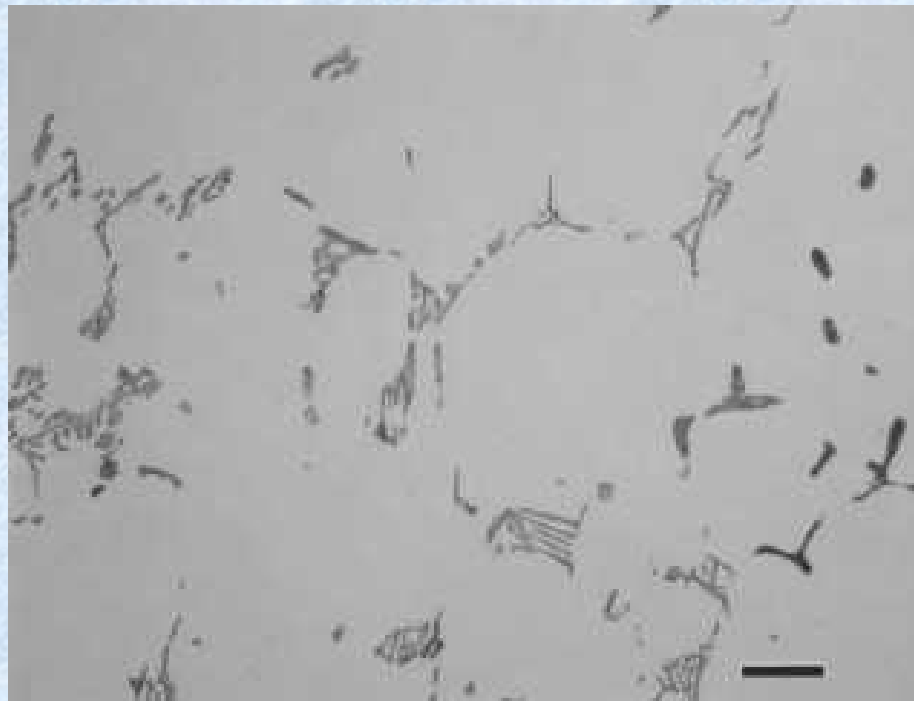


As-cast (concast) 3004 aluminum (Al – 1.25% Mn – 1.05% Mg) tint etched with Weck’s reagent and viewed with crossed polars plus sensitive tint. Magnification bar is 50 μ m long. Reveals segregation (“coring”) within the dendrites and intermetallics between the dendrites.

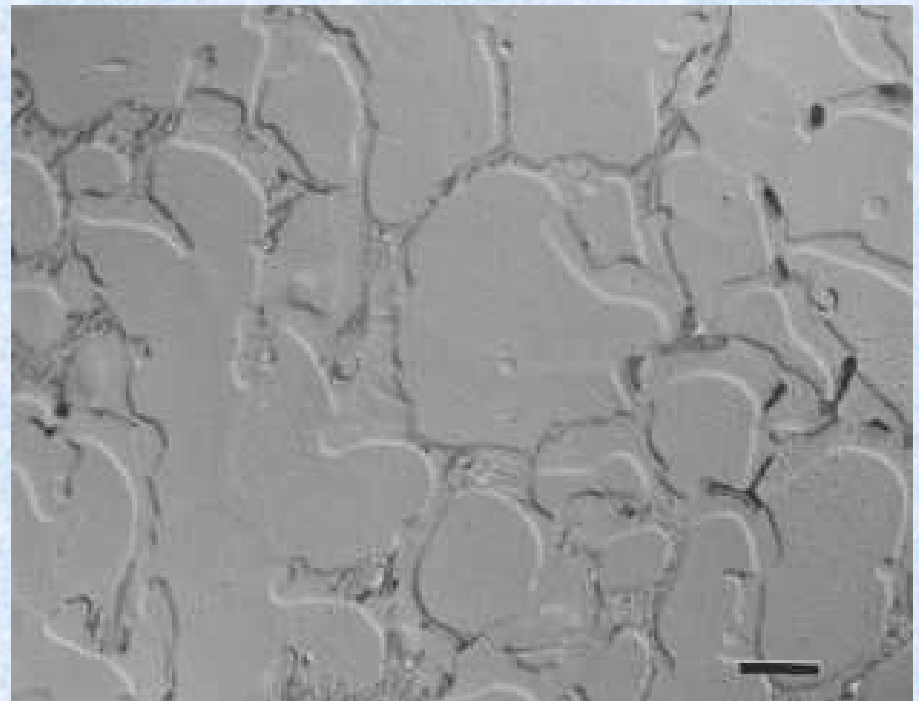


**As-cast (concast) 3004 aluminum (Al – 1.25% Mn – 1.05% Mg) etched with Keller's reagent.
Magnification bar is 20 μm long. Reveals intermetallics between the dendrites.**

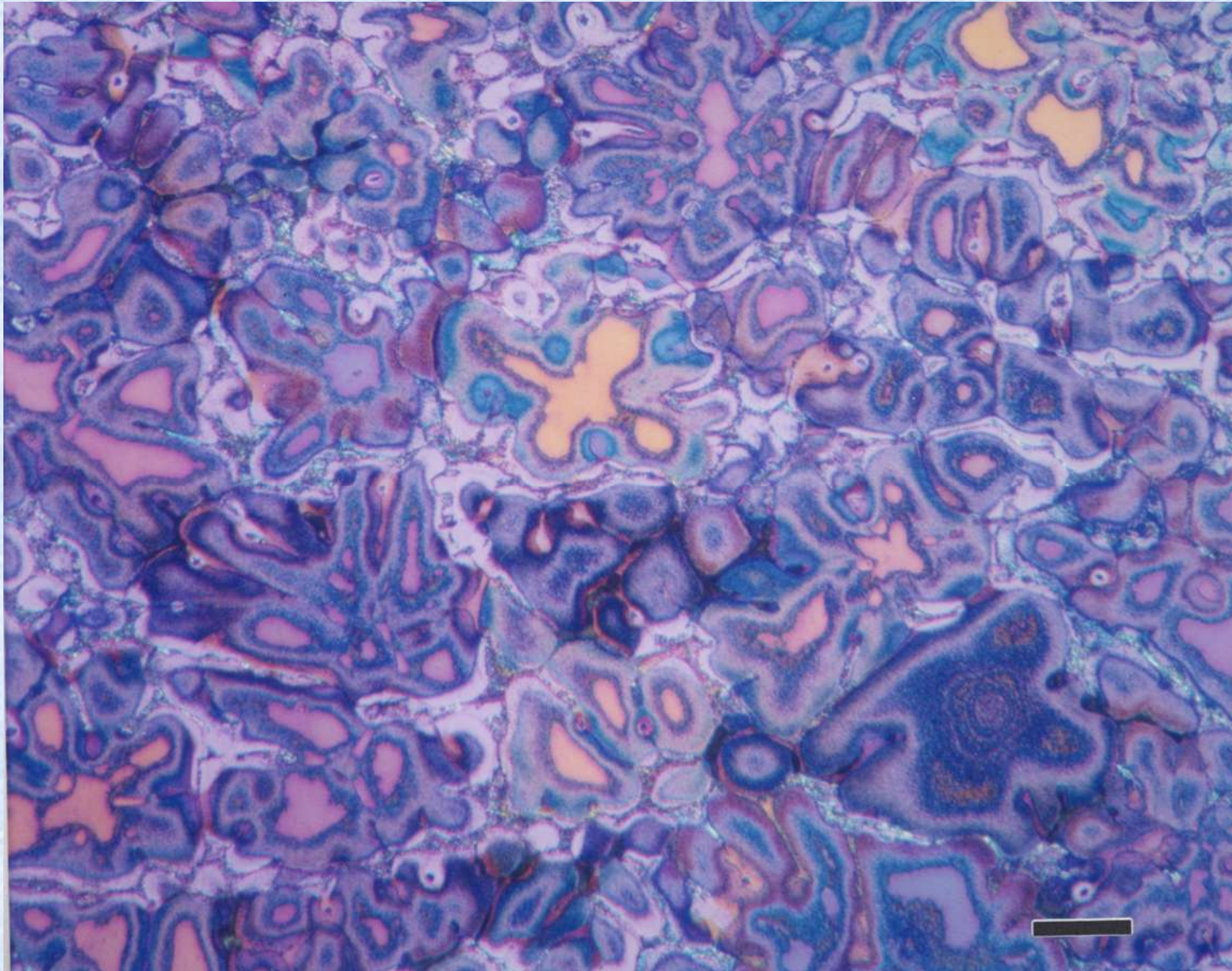
Bright Field



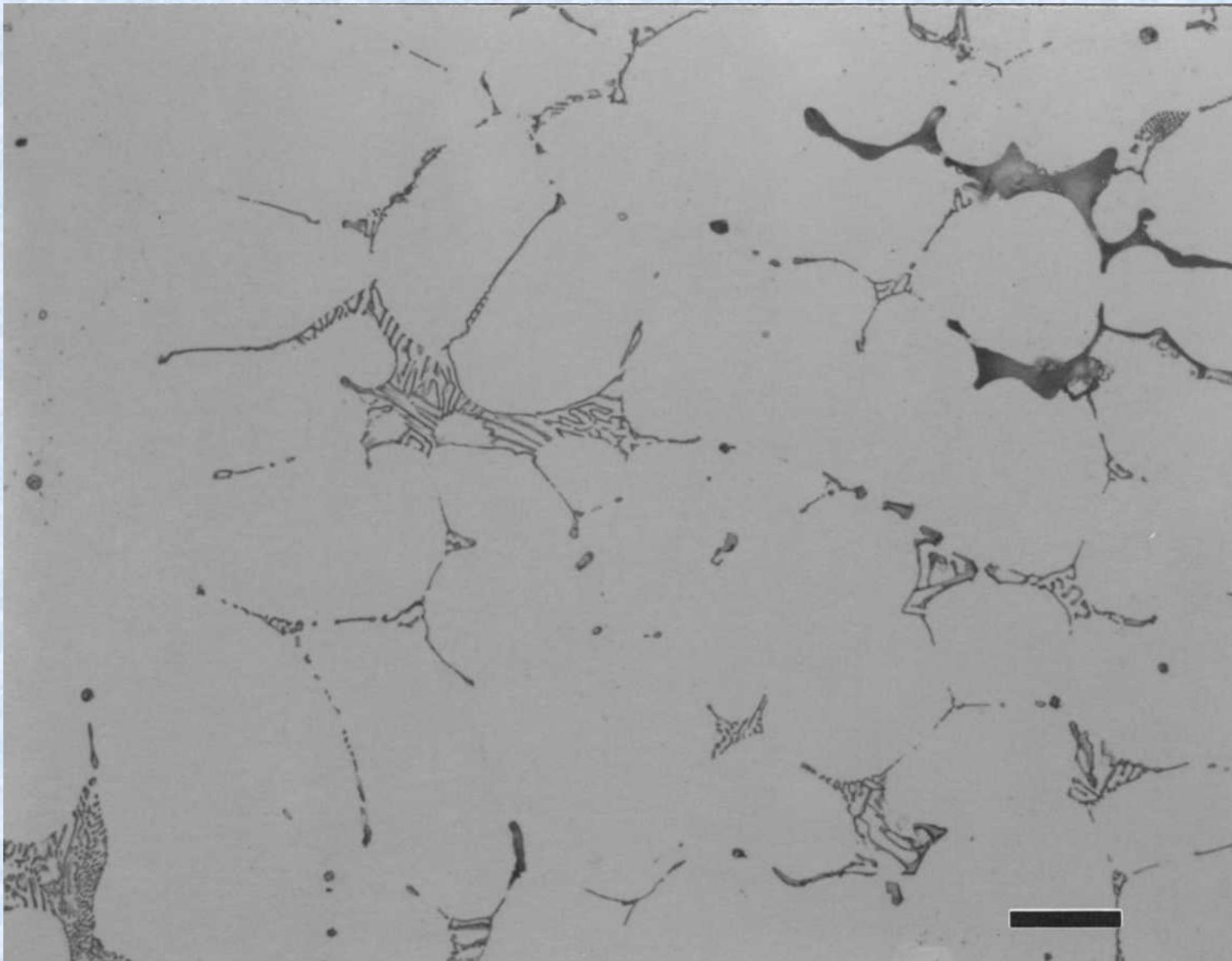
Differential Interference Contrast



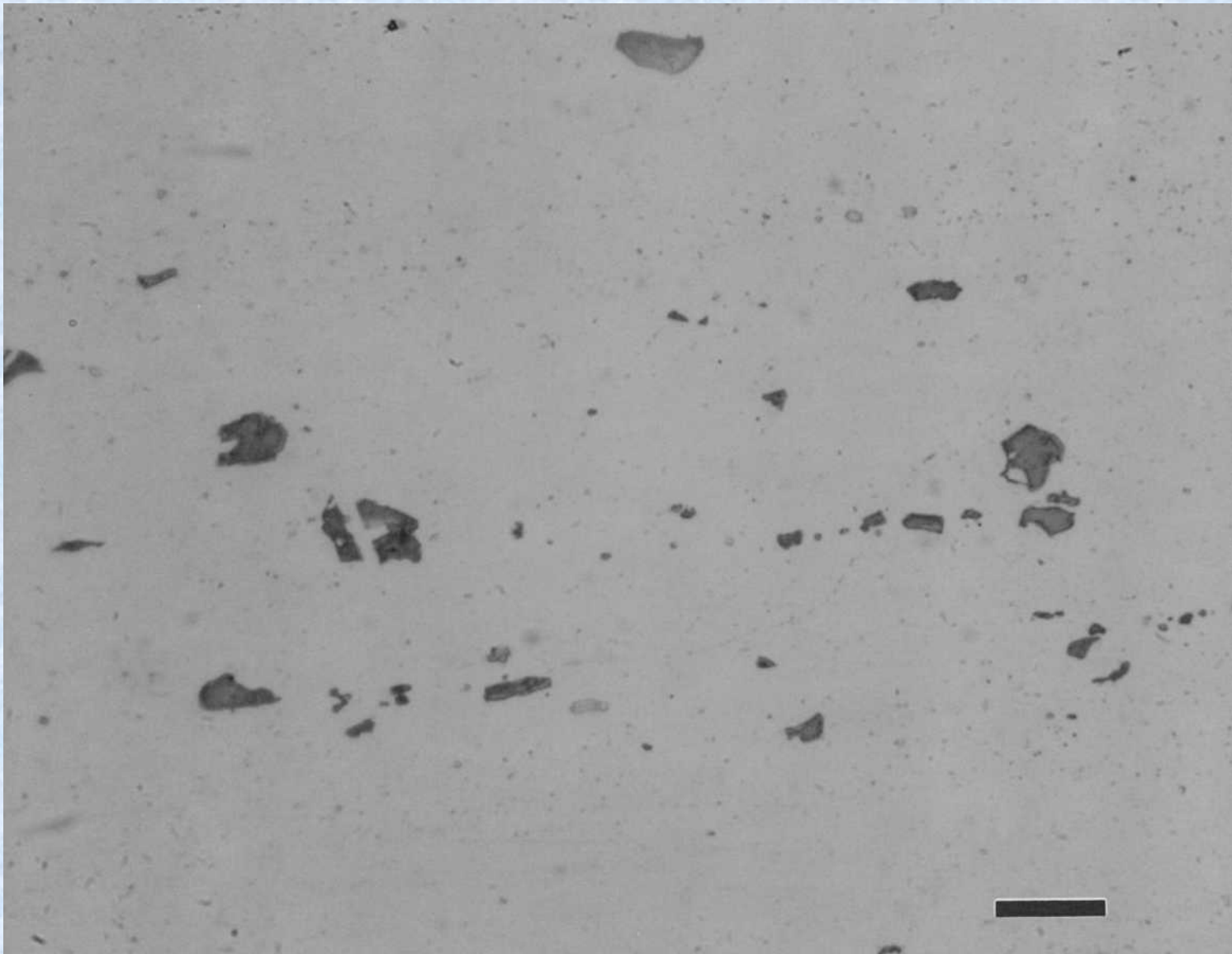
As-cast 3004 aluminum (Al – 1.25% Mn – 1.05% Mg) etched with Keller’s reagent. Magnification bars are both 20 μm long and the same field is shown, in bright field (left) and in Nomarski DIC (right). The dendrites are visible using DIC but not in bright field. The intermetallic particles between the dendrites are easier to see in bright field.



As-cast (concast) 3105 aluminum (Al – 0.55% Mn – 0.5% Mg) tint etched with Weck’s reagent and viewed with crossed polars plus sensitive tint. Magnification bar is 50 μ m long. Reveals segregation (“coring”) within the dendrites and intermetallics between the dendrites.



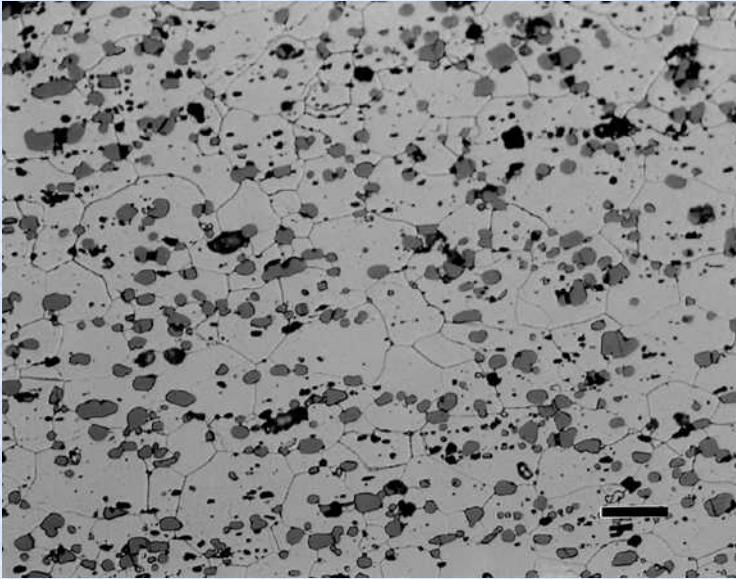
As-cast (concast) 3105 aluminum (Al – 0.55% Mn – 0.5% Mg) etched with Keller’s reagent. Magnification marker is 20 μm long. Reveals the intermetallic particles between the dendrites (not visible).



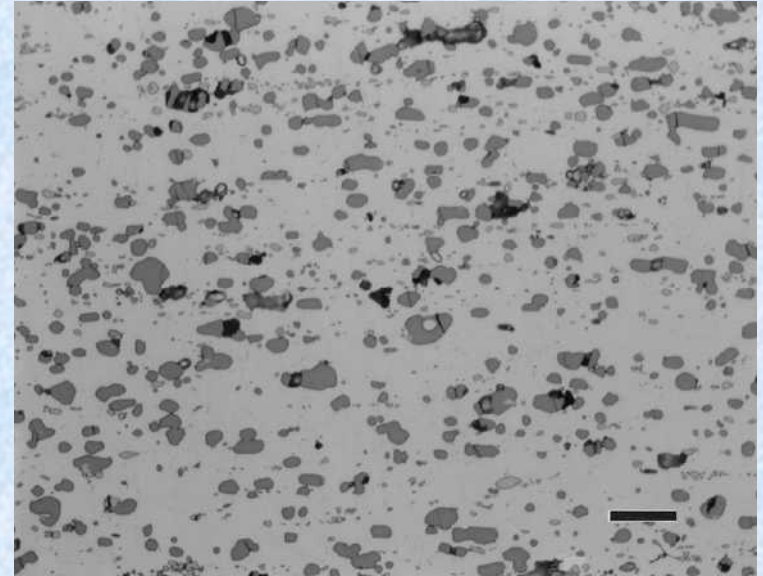
Extruded Al – 4.9 Mg – 0.2% Si – 0.2% Fe – 0.5% Mn etched with Keller’s reagent. Magnification bar is 10 μm long. Intermetallics are Mg_2Si and $(\text{Fe,Mn})\text{Al}_6$.

4032-T6

Keller's



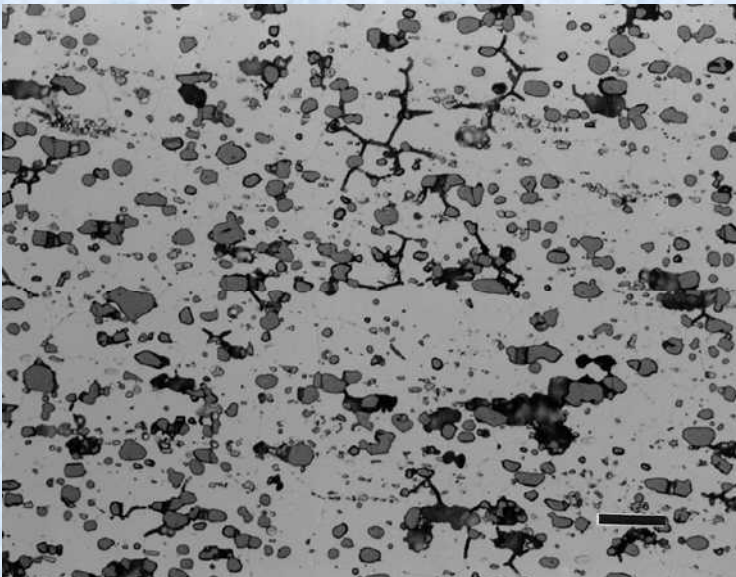
NaF-NaOH



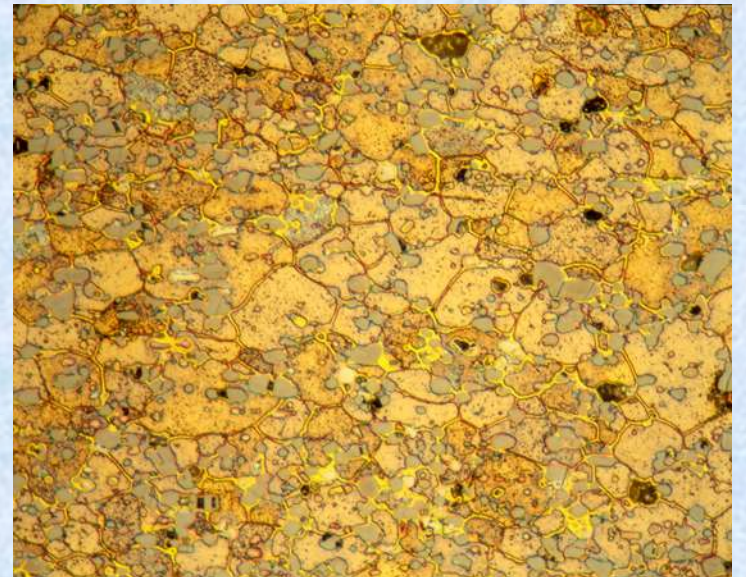
B&W –
Bars are
20- μ m long
500X

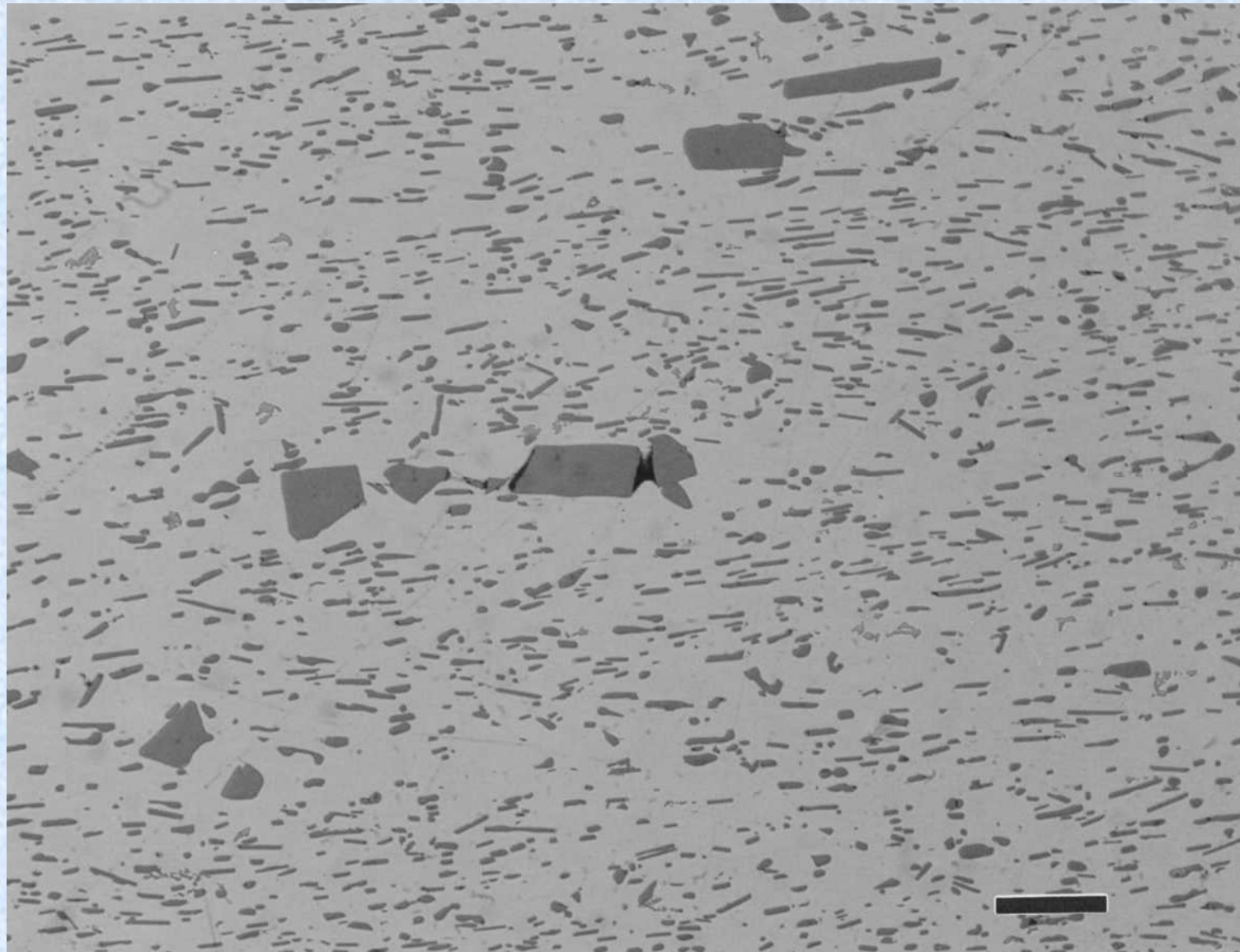
Color is
500X

Graff-Sargent



Weck's

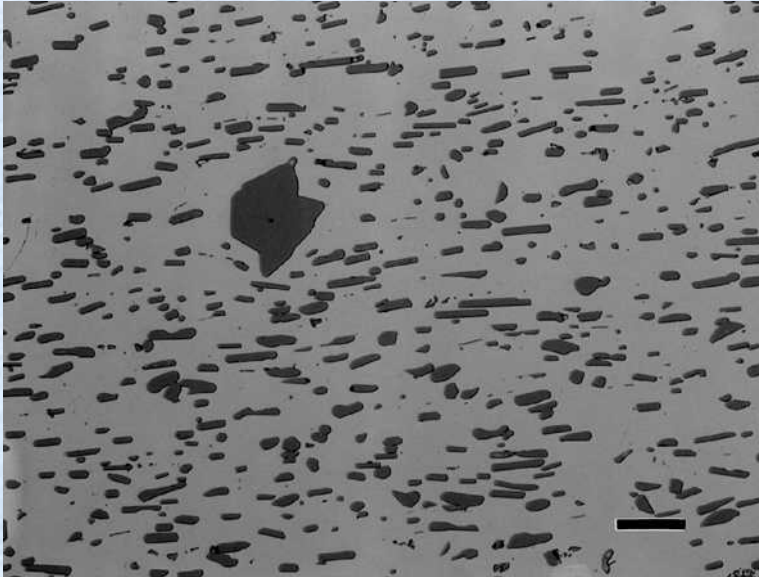




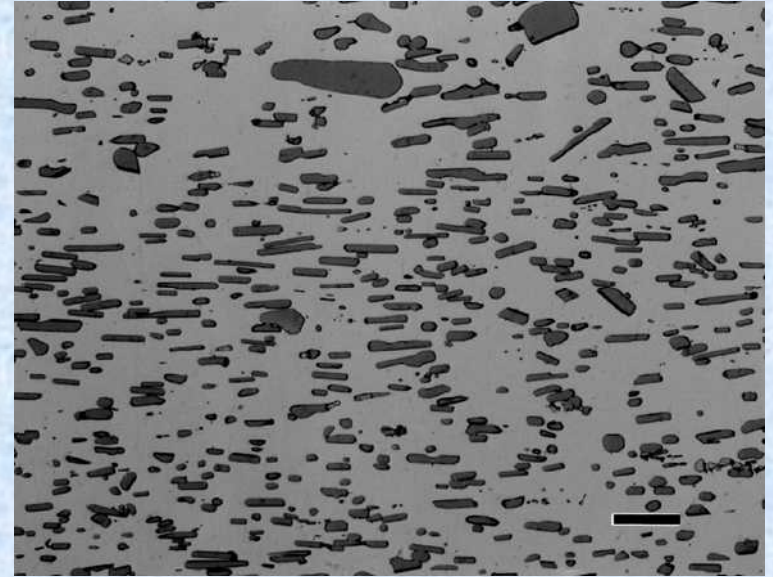
Wrought 4147 aluminum (Al – 12% Si – 0.3% Mg) in the as-polished condition showing the silicon particles elongated in the hot working direction (horizontal). Magnification bar is 50 μm long.

4147

Keller's



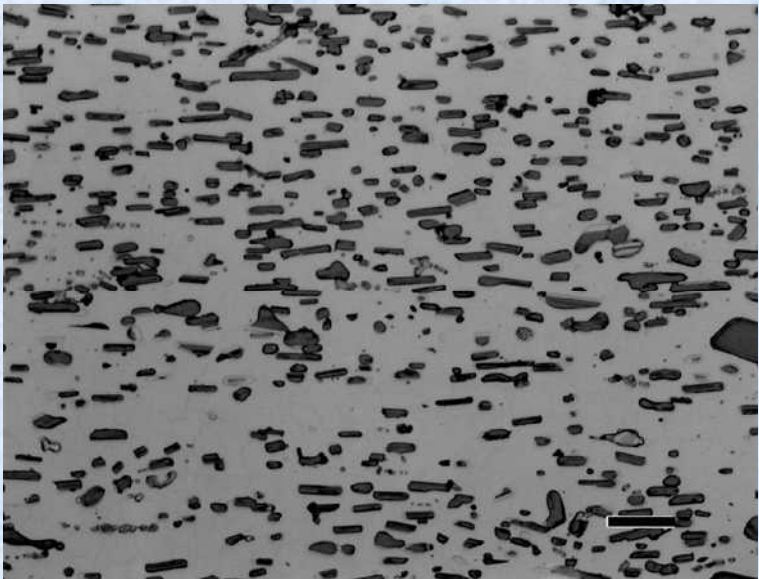
NaF-NaOH



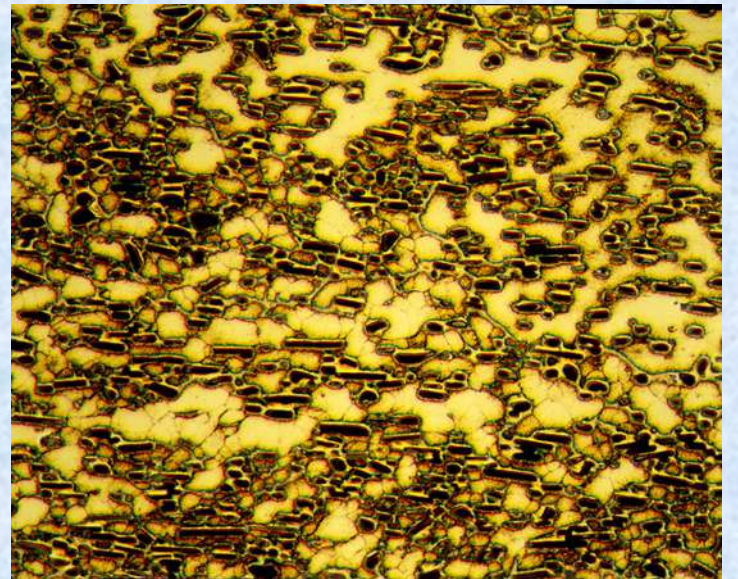
B&W –
Bars are
20- μ m long
500X

Color is
500X

Graff-Sargent

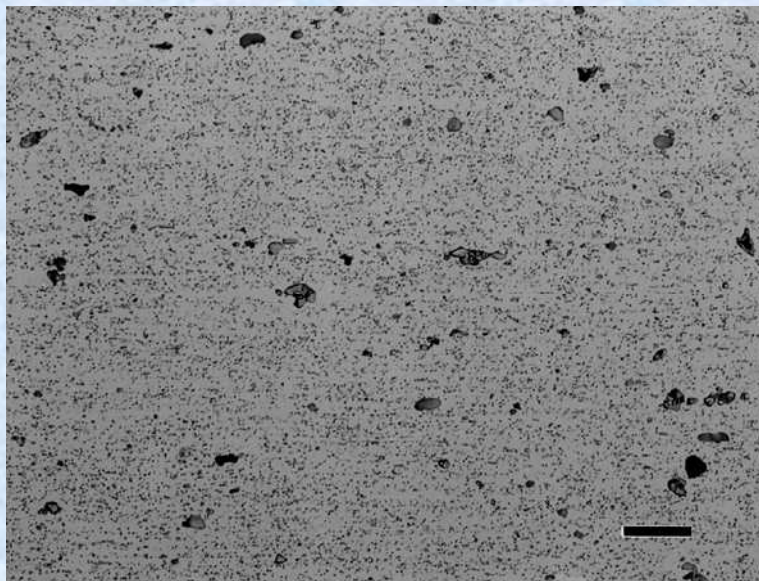


Weck's

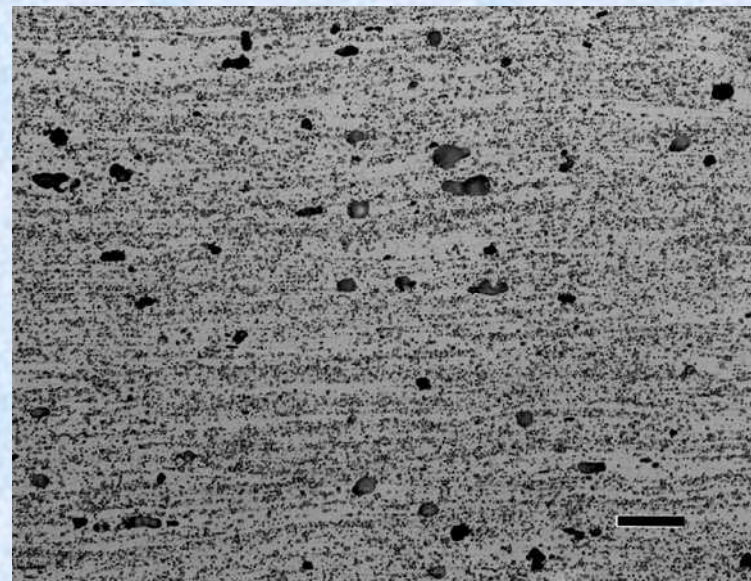


5083-H321

Keller's



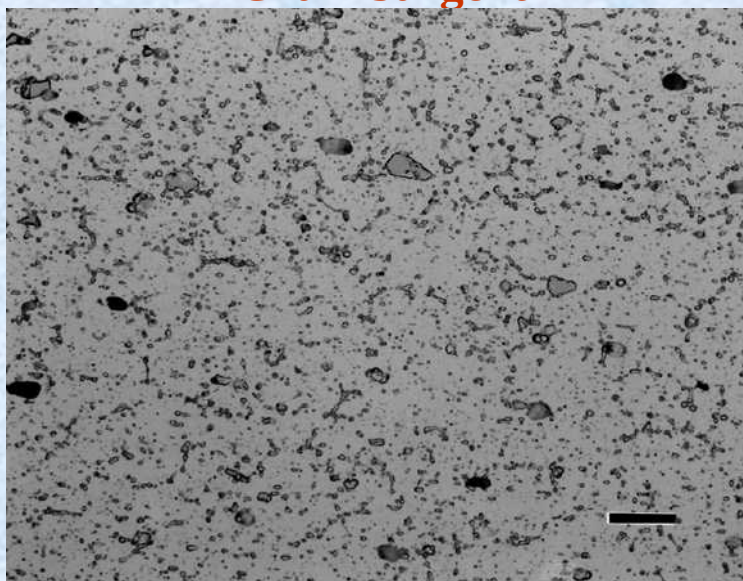
NaF-NaOH



**B&W –
Bars are
20- μ m long
500X**

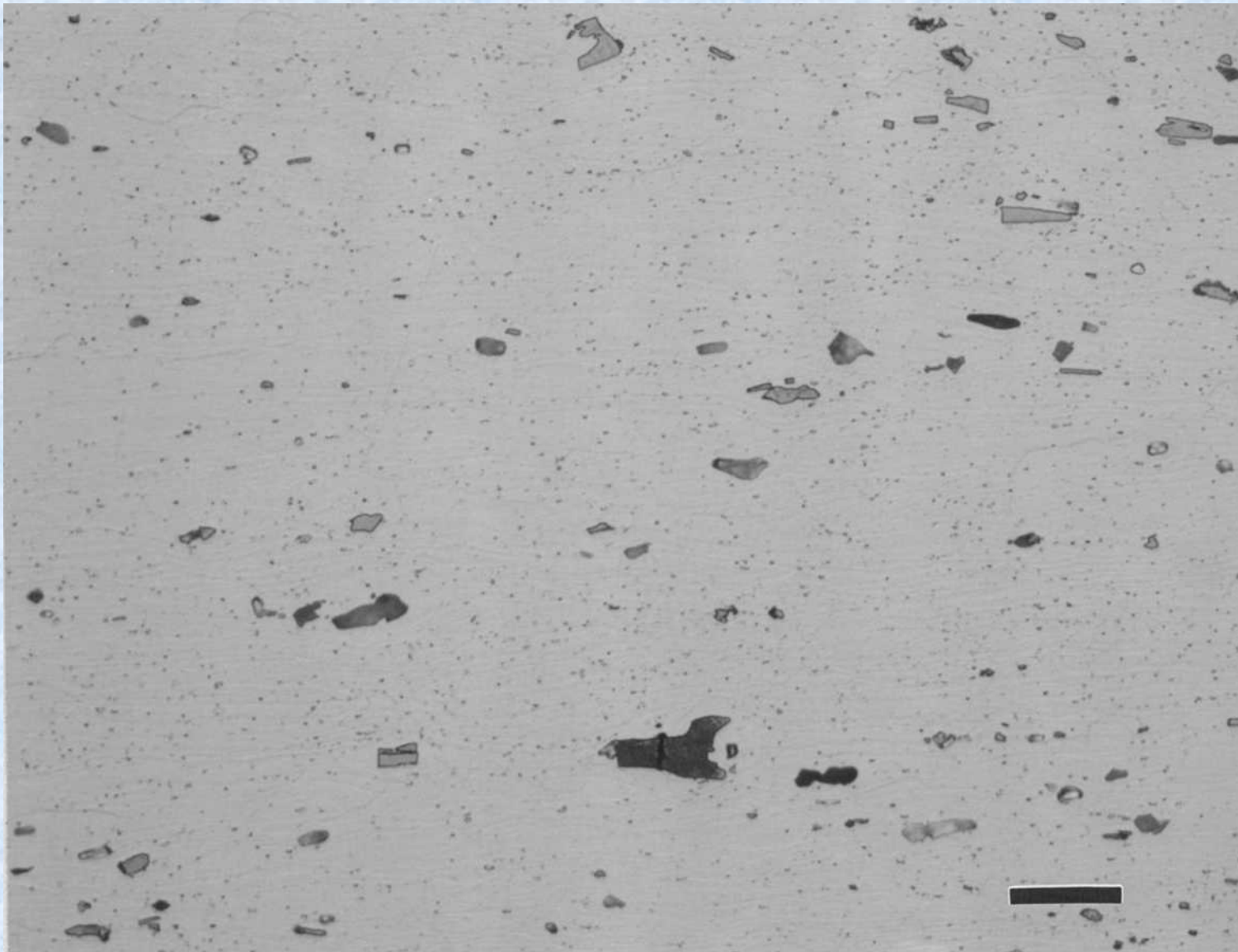
**Color is
500X**

Graff-Sargent

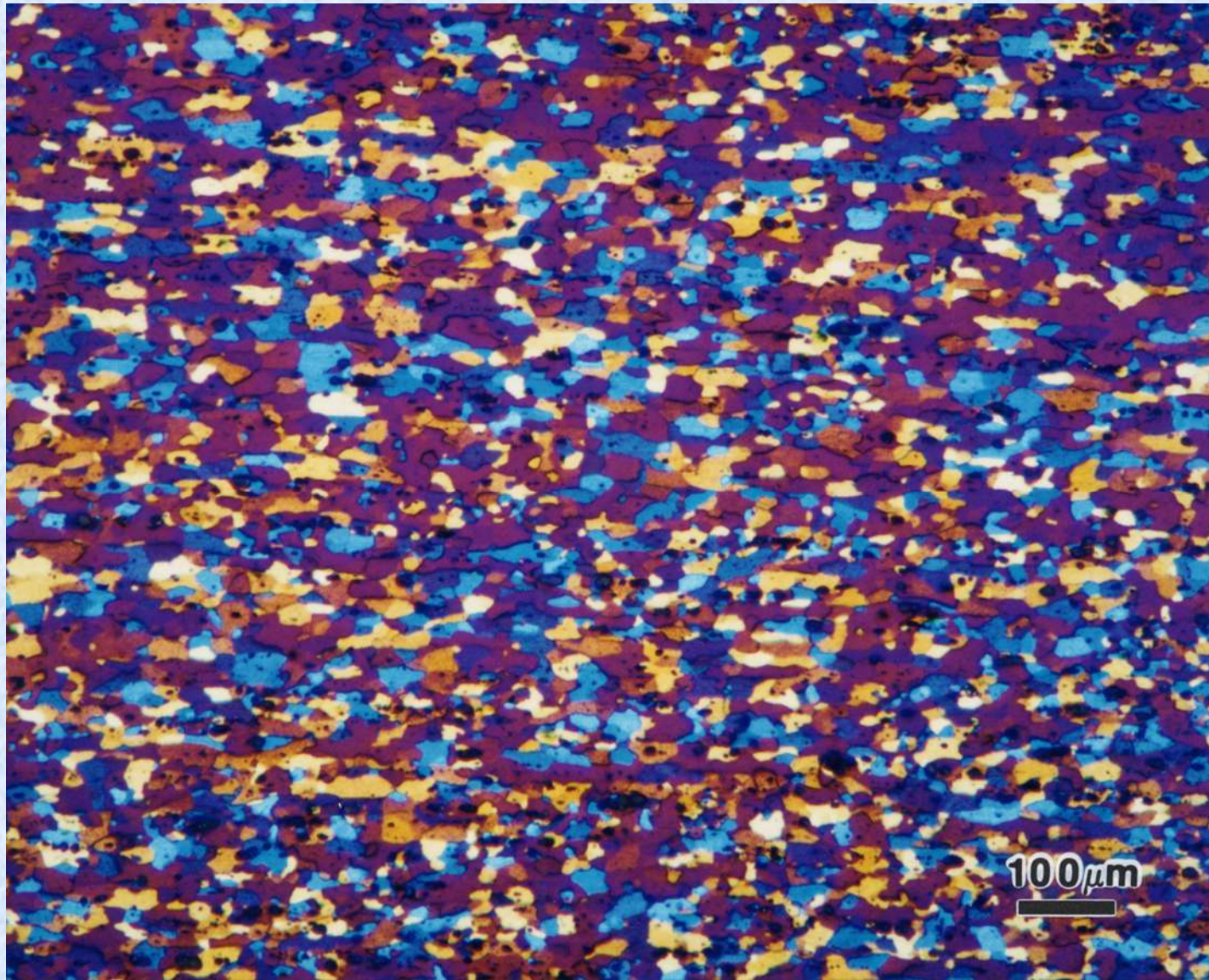


Weck's

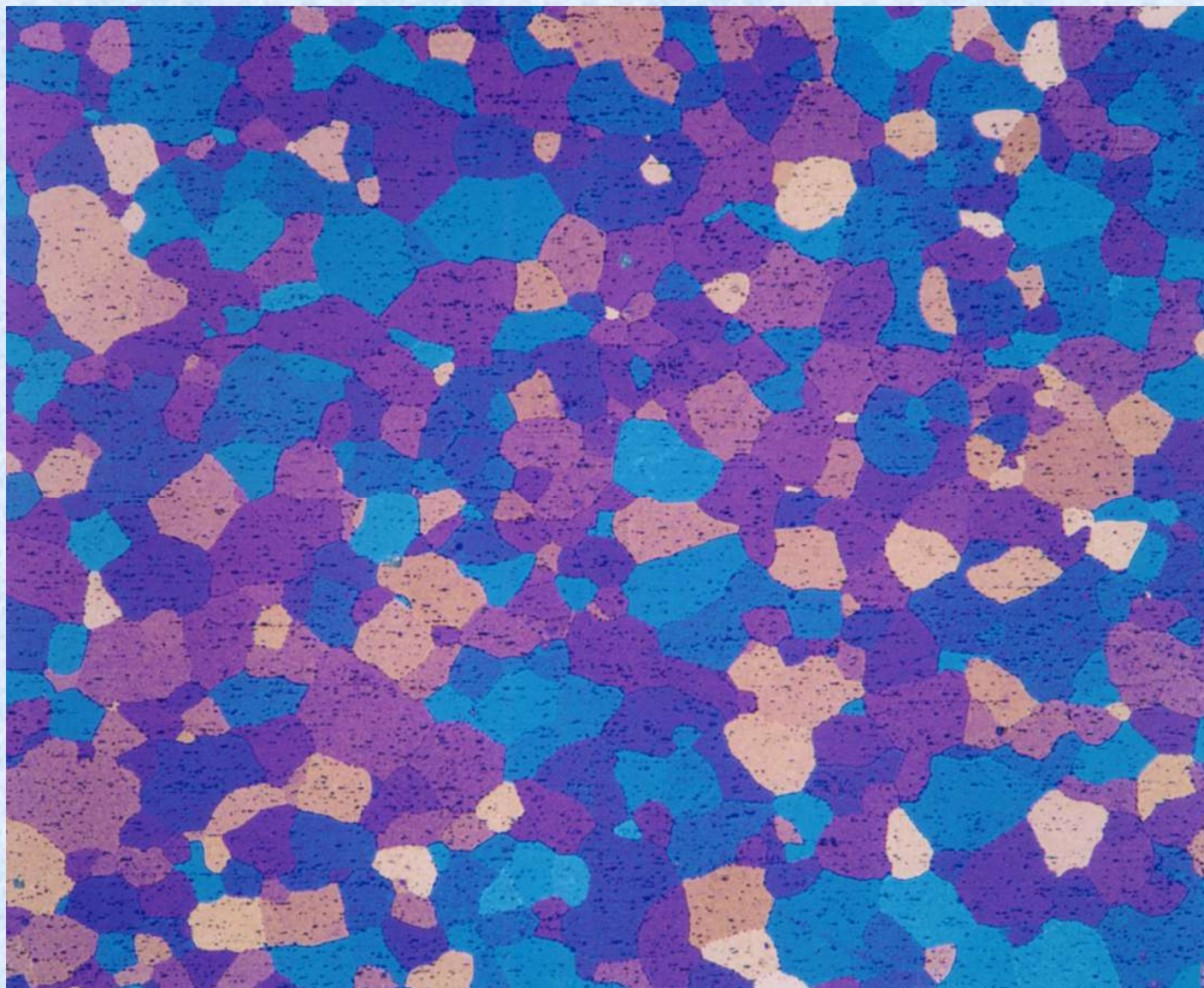




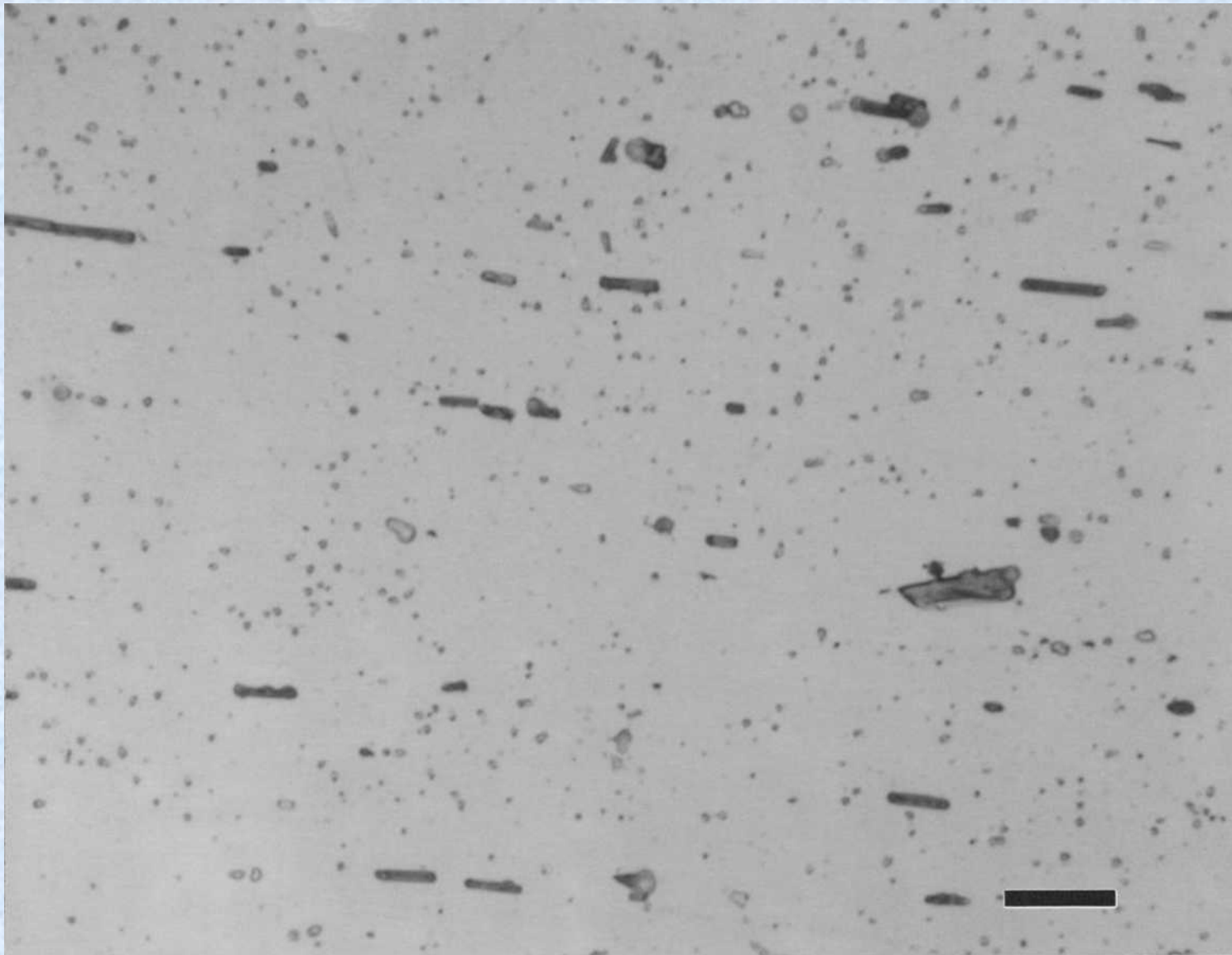
Wrought 5754-F aluminum strip (Al – 3.2% Mg – 0.4% Mn + Cr) etched with 0.5% HF. Magnification bar is 20 μm long.



Wrought 5754-F aluminum strip (Al – 3.2% Mg – 0.4% Mn + Cr) anodized with Barker’s reagent (30 V dc, 2 min.). The strip was cold worked and annealed at 343 °C (650 °F) for 2 h. The grain structure is fully recrystallized.



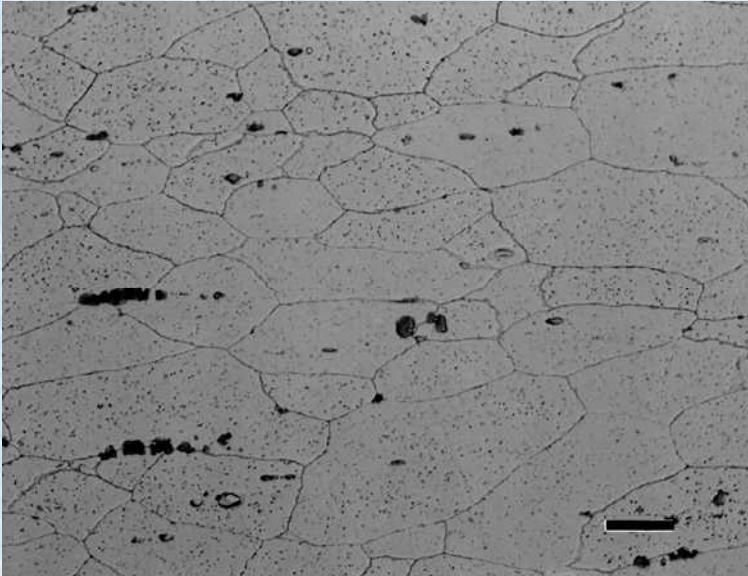
Wrought 6005 aluminum (Al – 0.5% Mg – 0.8% Si) anodized with Barker's reagent (20 V dc, 2 min.) revealing an equiaxed alpha grain structure. Original at 50X. Viewed with crossed polarized light plus sensitive tint.



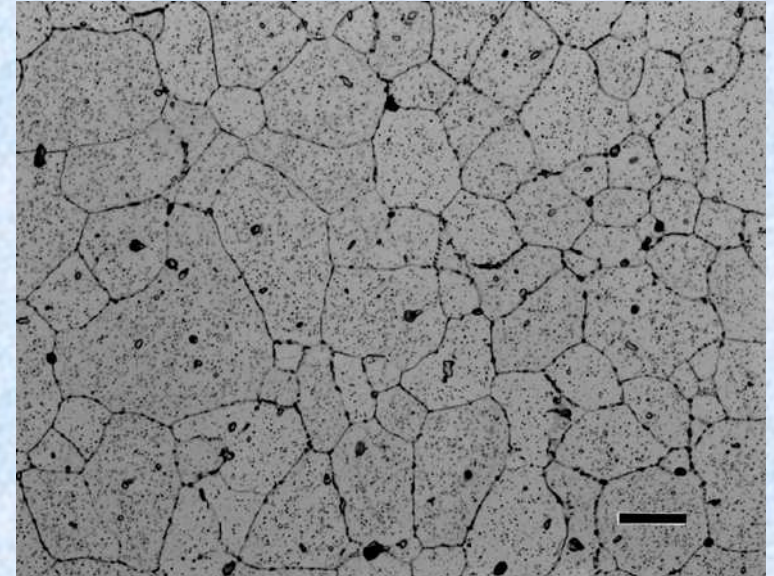
Wrought 6005-T5 aluminum (Al – 0.5% Mg – 0.8% Si) etched with Keller's reagent showing the intermetallic presipitates. Magnification bar is 10 μm long.

6013-T8

Keller's (longitudinal)



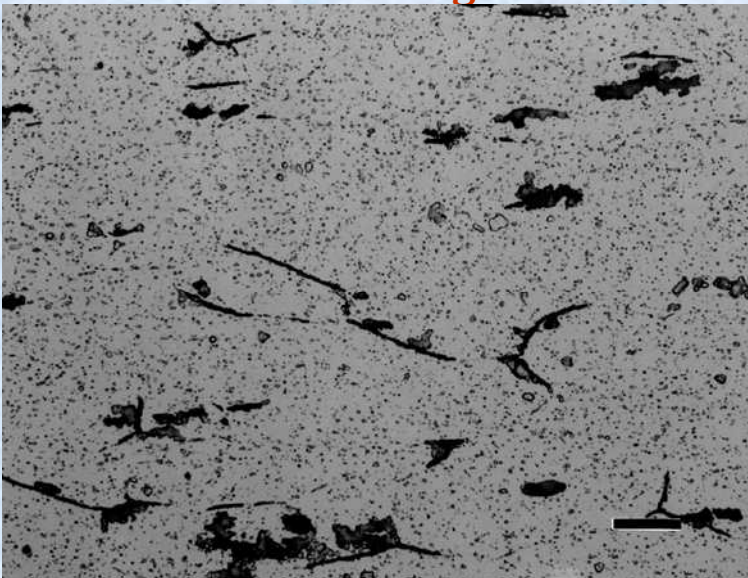
NaF-NaOH (transverse)



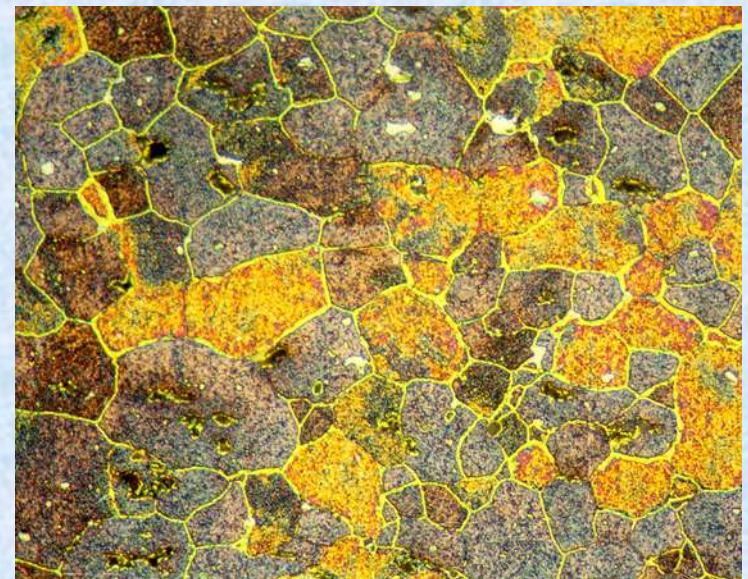
**B&W –
Bars are
20- μ m long
500X**

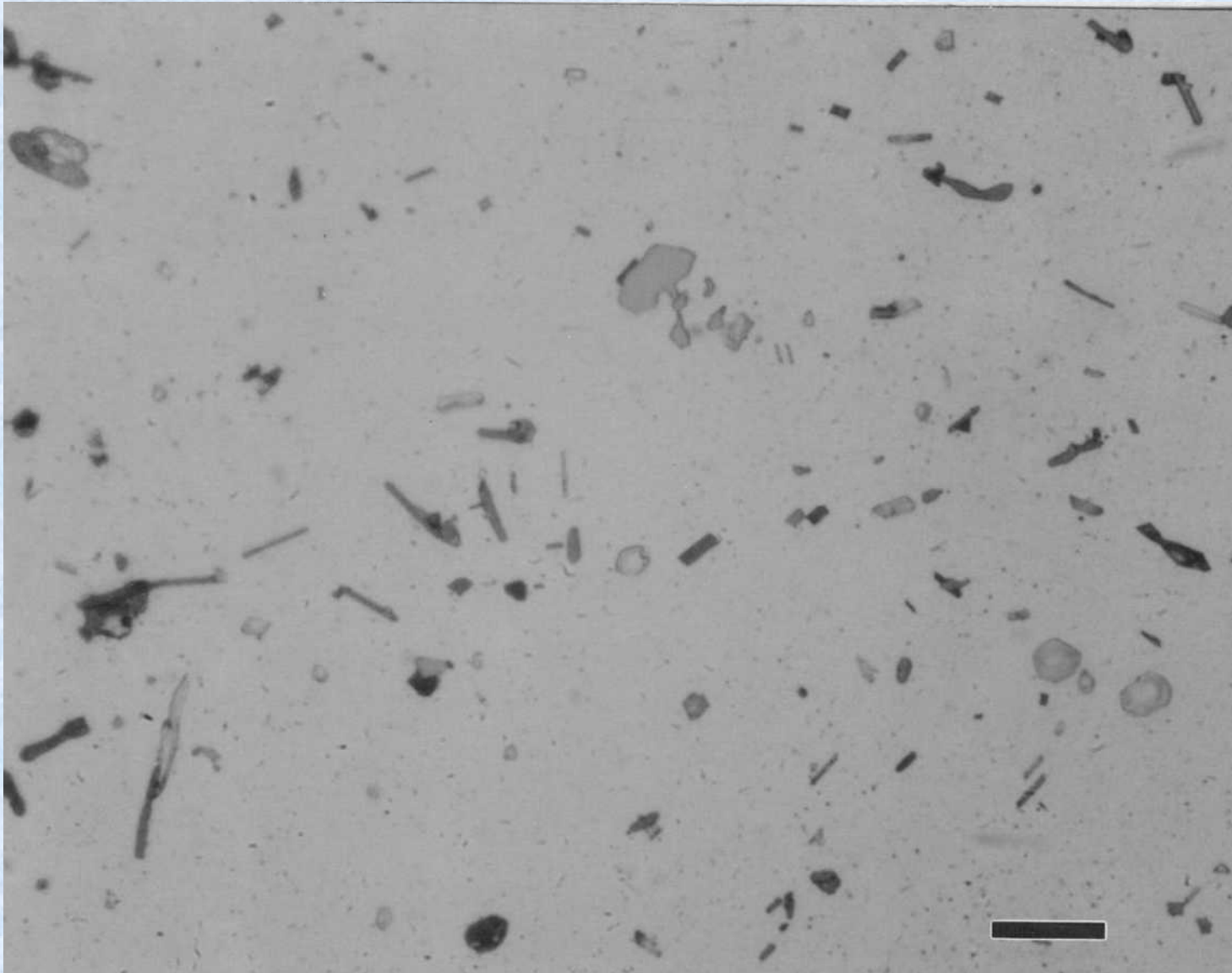
**Color is
500X**

Graff-Sargent

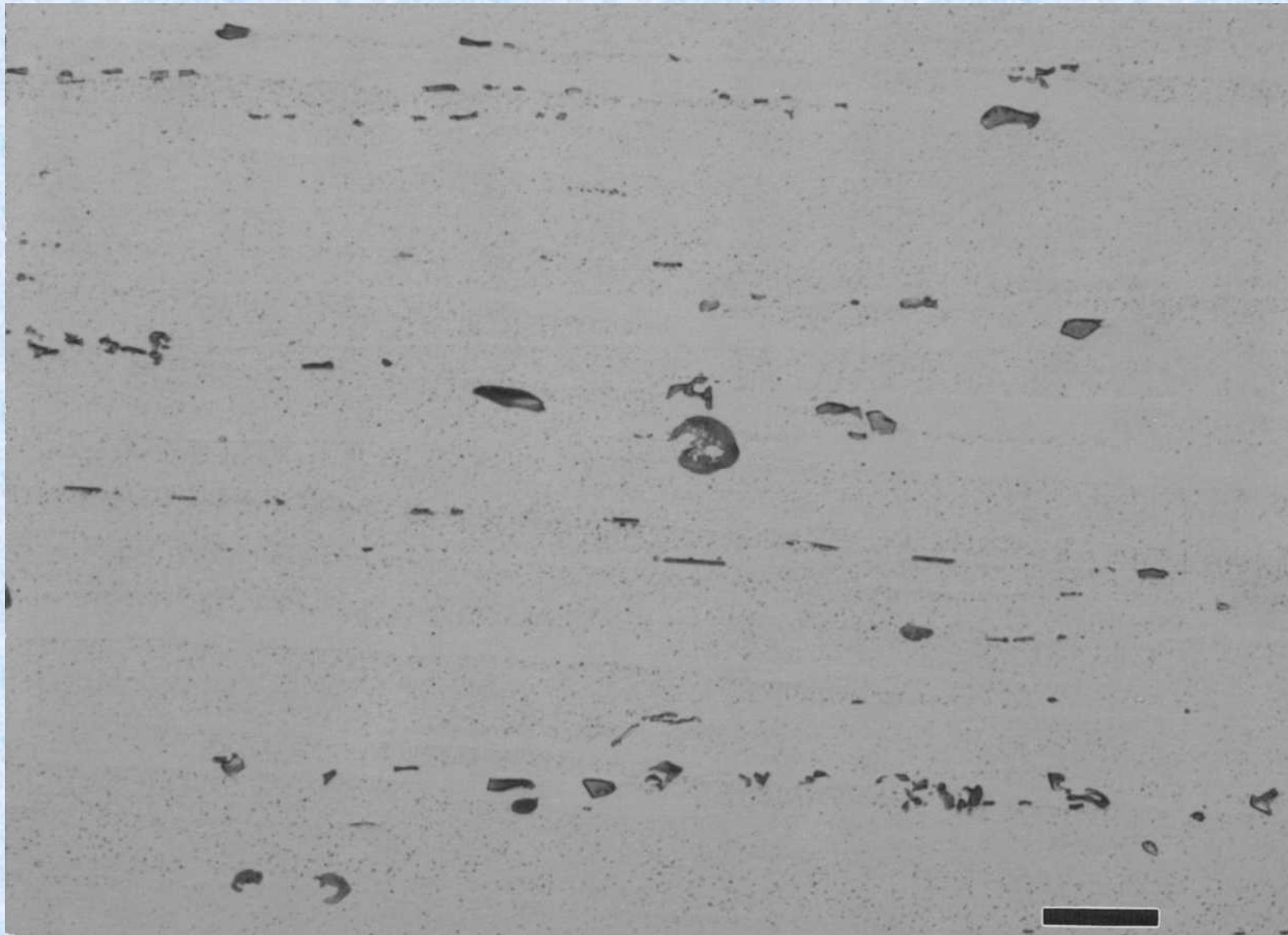


Weck's

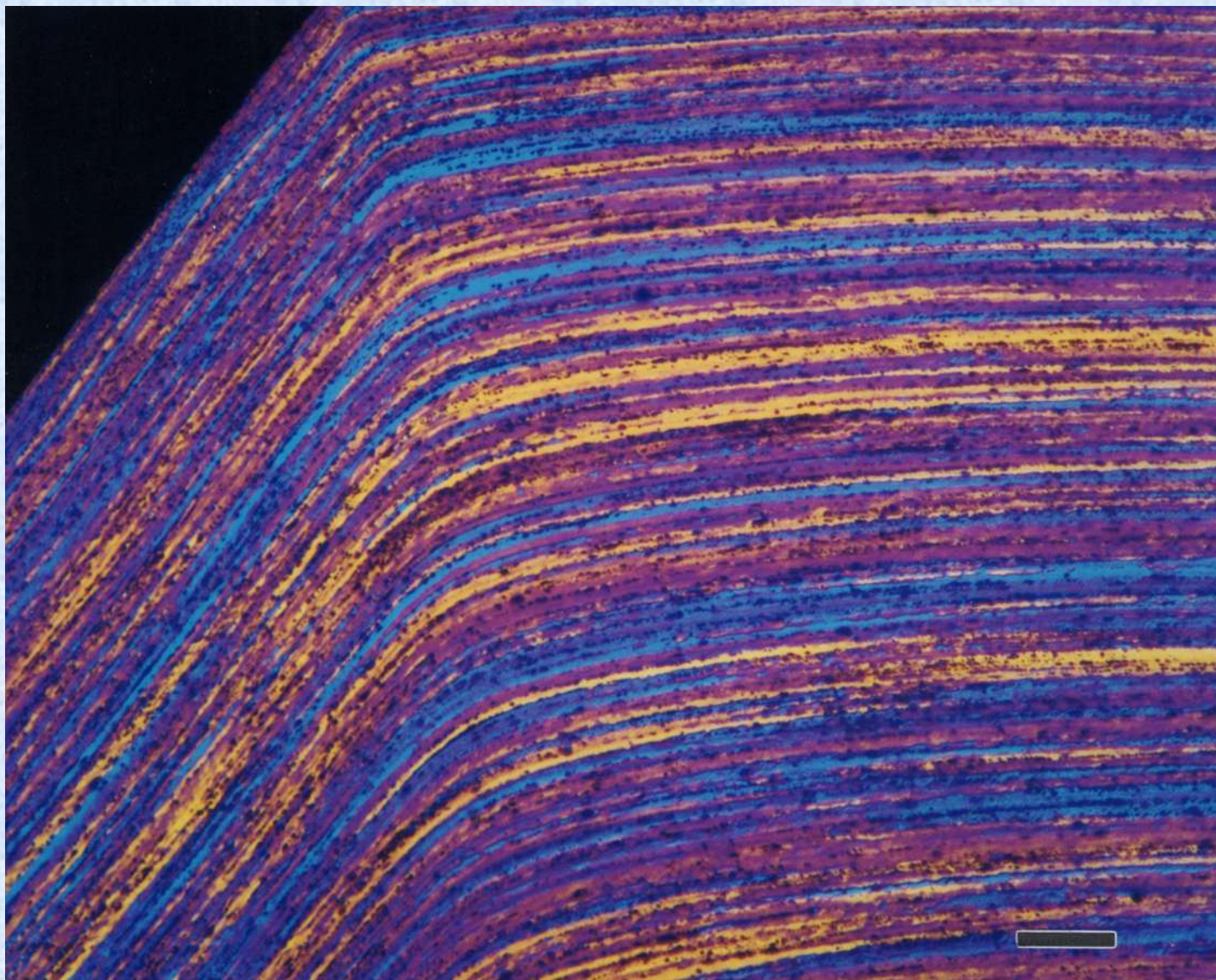




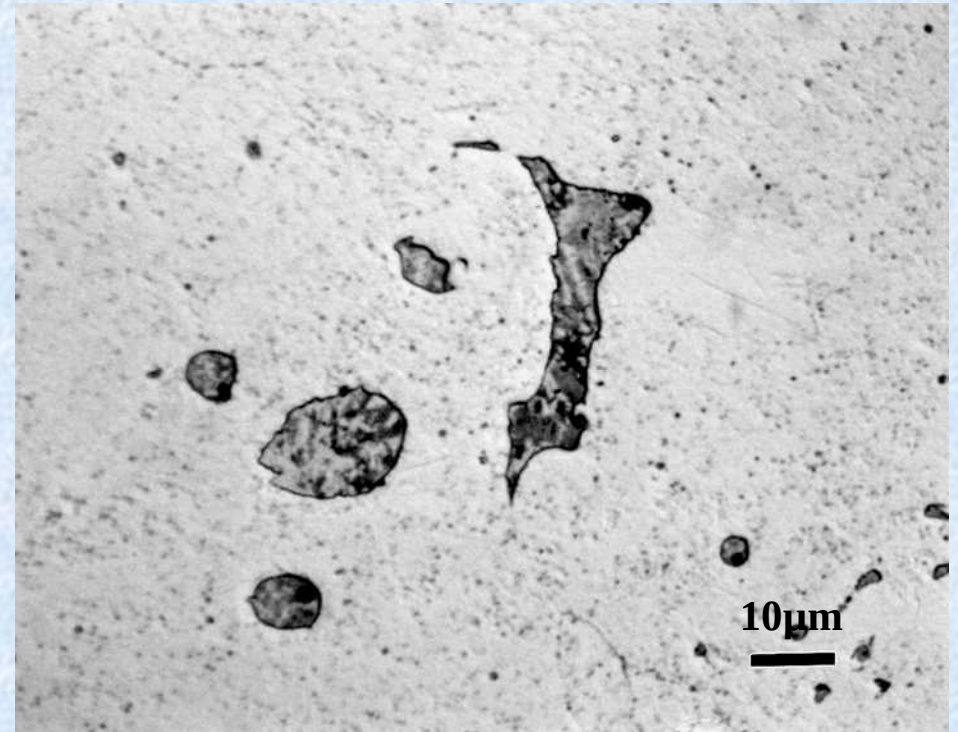
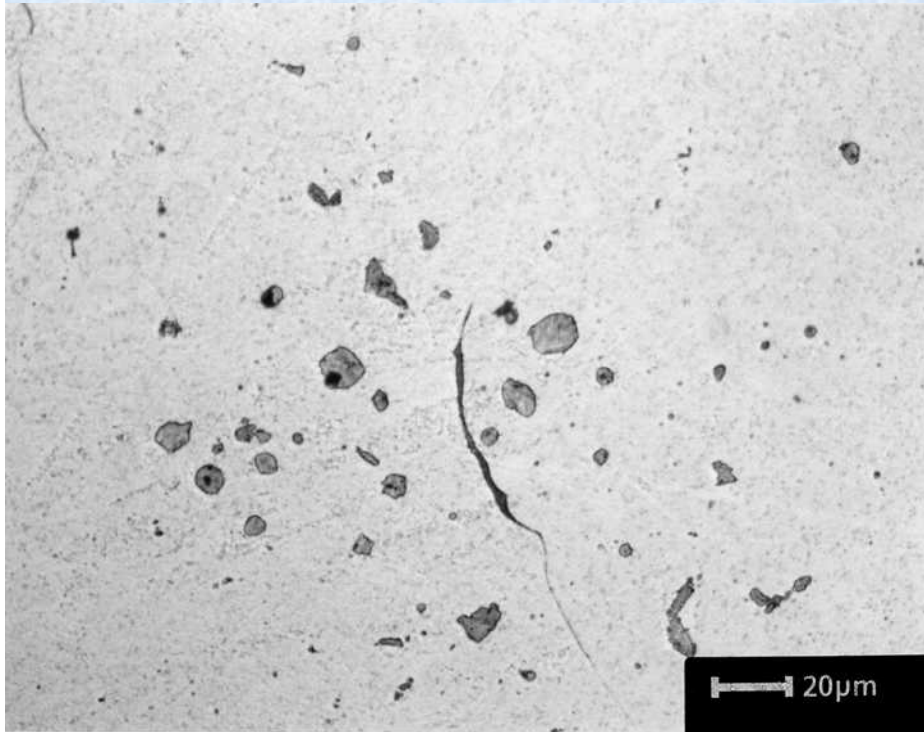
Wrought 6061-O annealed aluminum (Al – 1% Mg – 0.6% Si – 0.2% Cr – 0.27% Cu) etched with aqueous 0.5% HF to reveal the intermetallics. Magnification bar is 10 μm long.



Wrought 6061-T6 aluminum (Al – 1% Mg – 0.6% Si – 0.2% Cr – 0.27% Cu) extrusion (125 mm diameter) etched with Keller's reagent to reveal the intermetallics. Magnification bar is 20 μ m long.



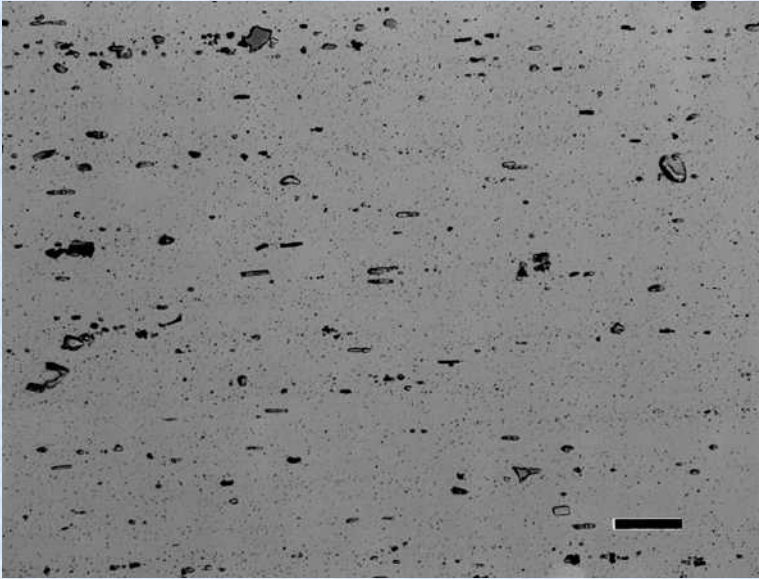
Sheared end of 6061-F (Al – 1% Mg – 0.6% Si – 0.2% Cr – 0.27% Cu) extruded rod anodized with Barker's reagent (30 V dc, 2 min.) revealing the heavily elongated grains from extruding and the compression of the sheared end. Magnification bar is 100 μ m long.



Incipient melting “rosettes” in 6061 alloy, 0.5% HF etch

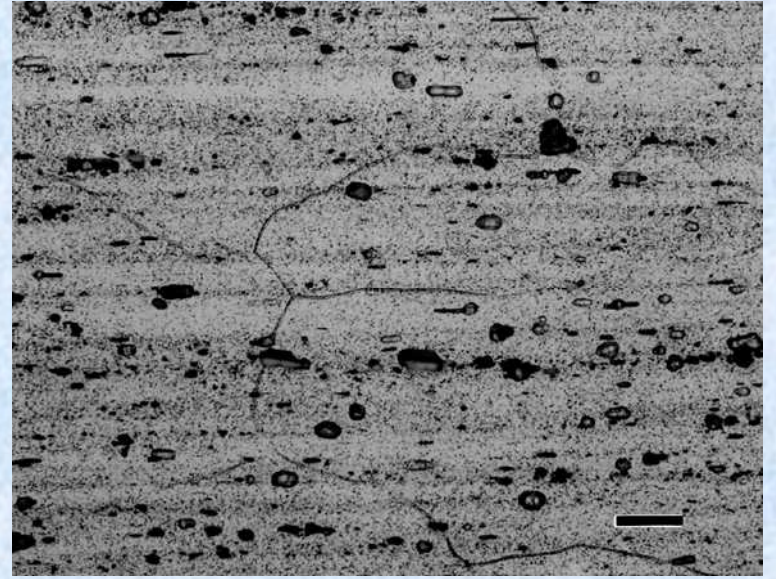
6061-T6511

Keller's

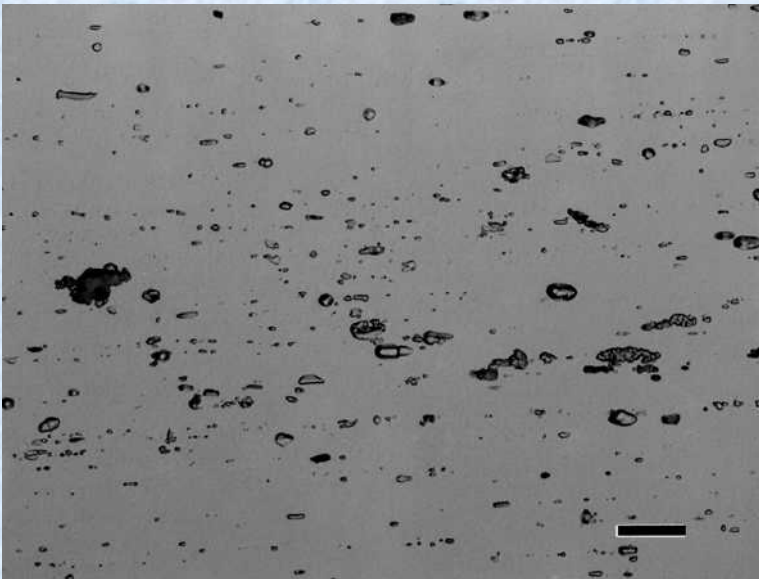


B&W –
Bars are
20- μ m long
500X

NaF-NaOH

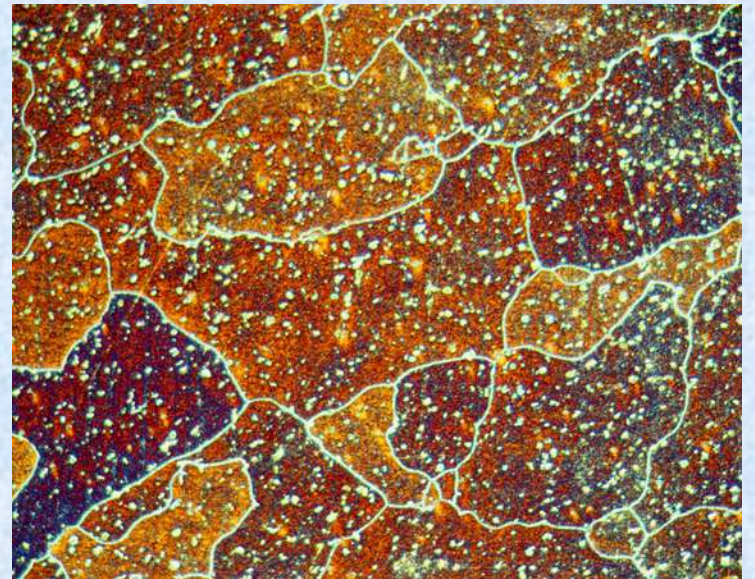


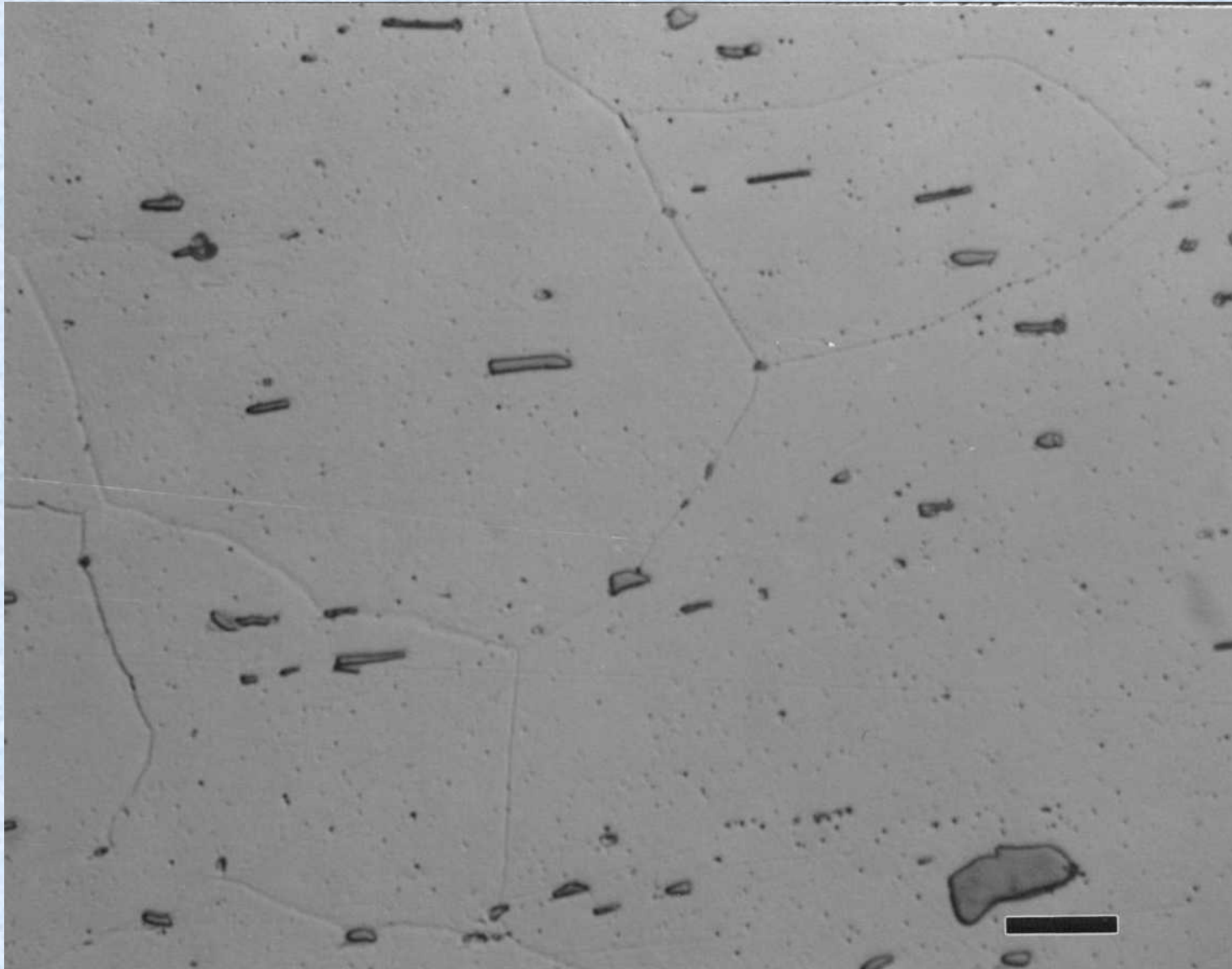
Graff-Sargent



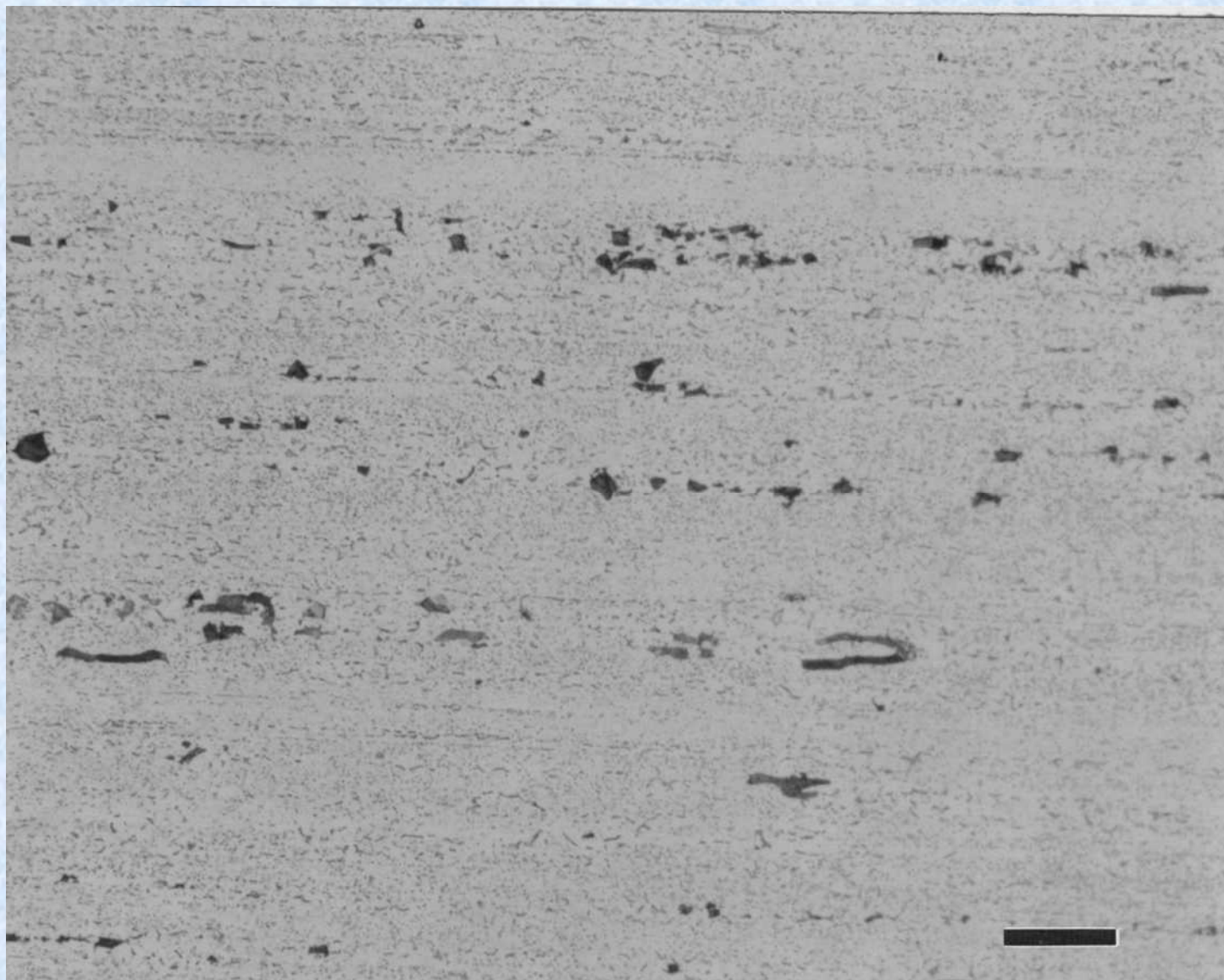
Color is
200X

Weck's





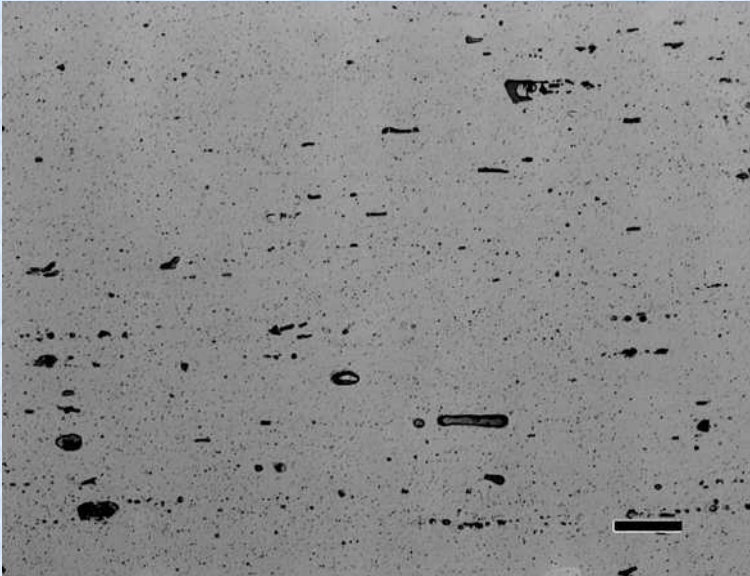
Wrought 6063-T5 aluminum (Al 0.7% Mg – 0.4% Si) etched with aqueous 0.5% HF revealing the alpha grain boundaries and intermetallic precipitates. Magnification bar is 10 μm long.



Extruded Al – 5.6% Zn – 2.5% Mg – 0.2% Si – 0.2% Fe – 0.5% Cu – 0.5% Mn etched with Keller's reagent revealing the intermetallic precipitates. Magnification bar is 20 μm long.

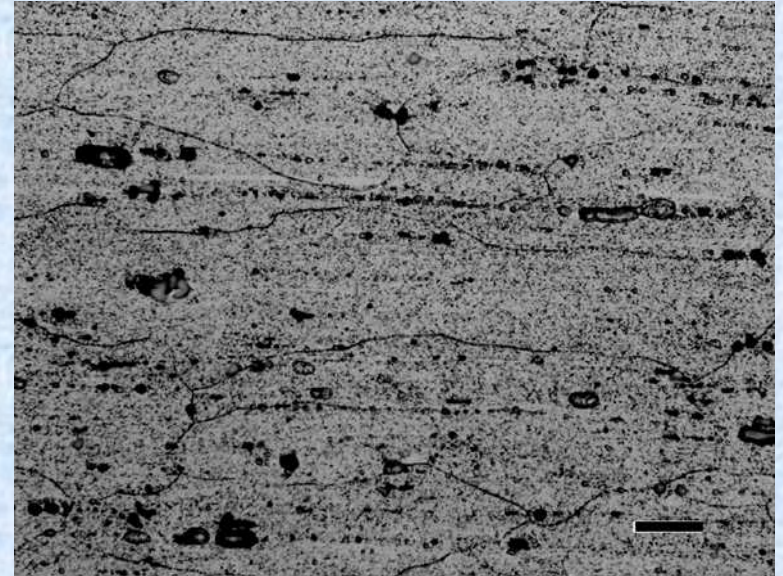
6262-T9

Keller's

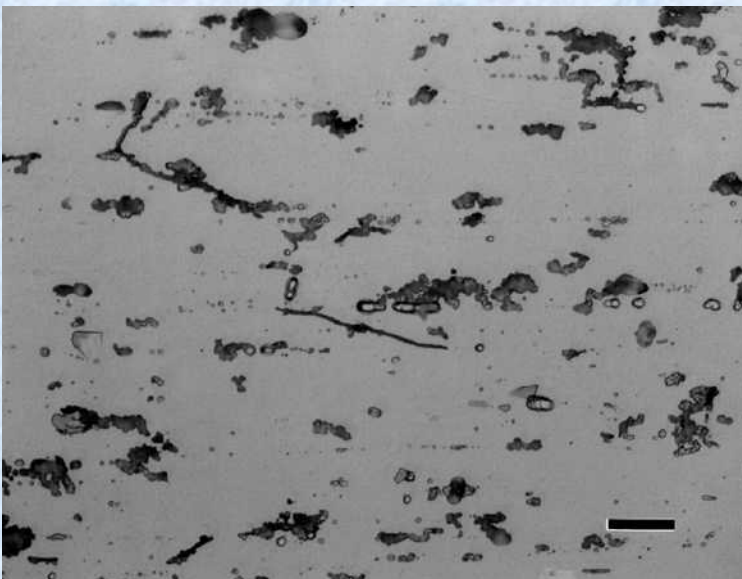


**B&W –
Bars are
20- μ m long
500X**

NaF-NaOH

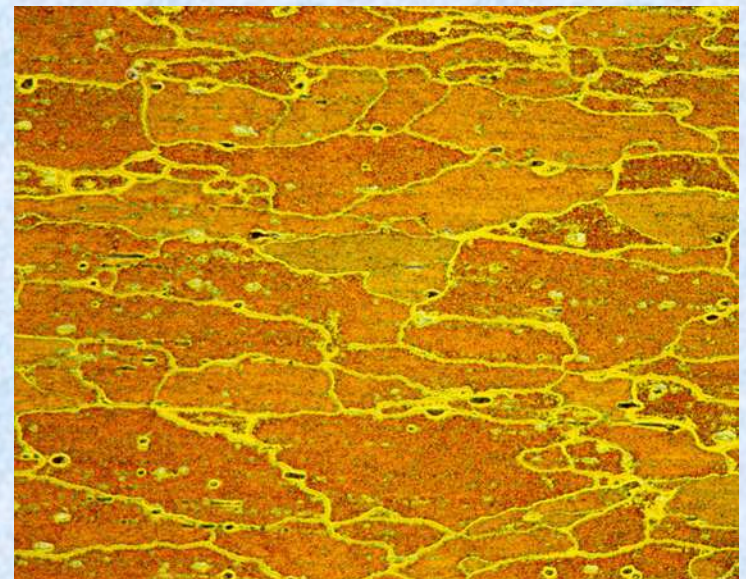


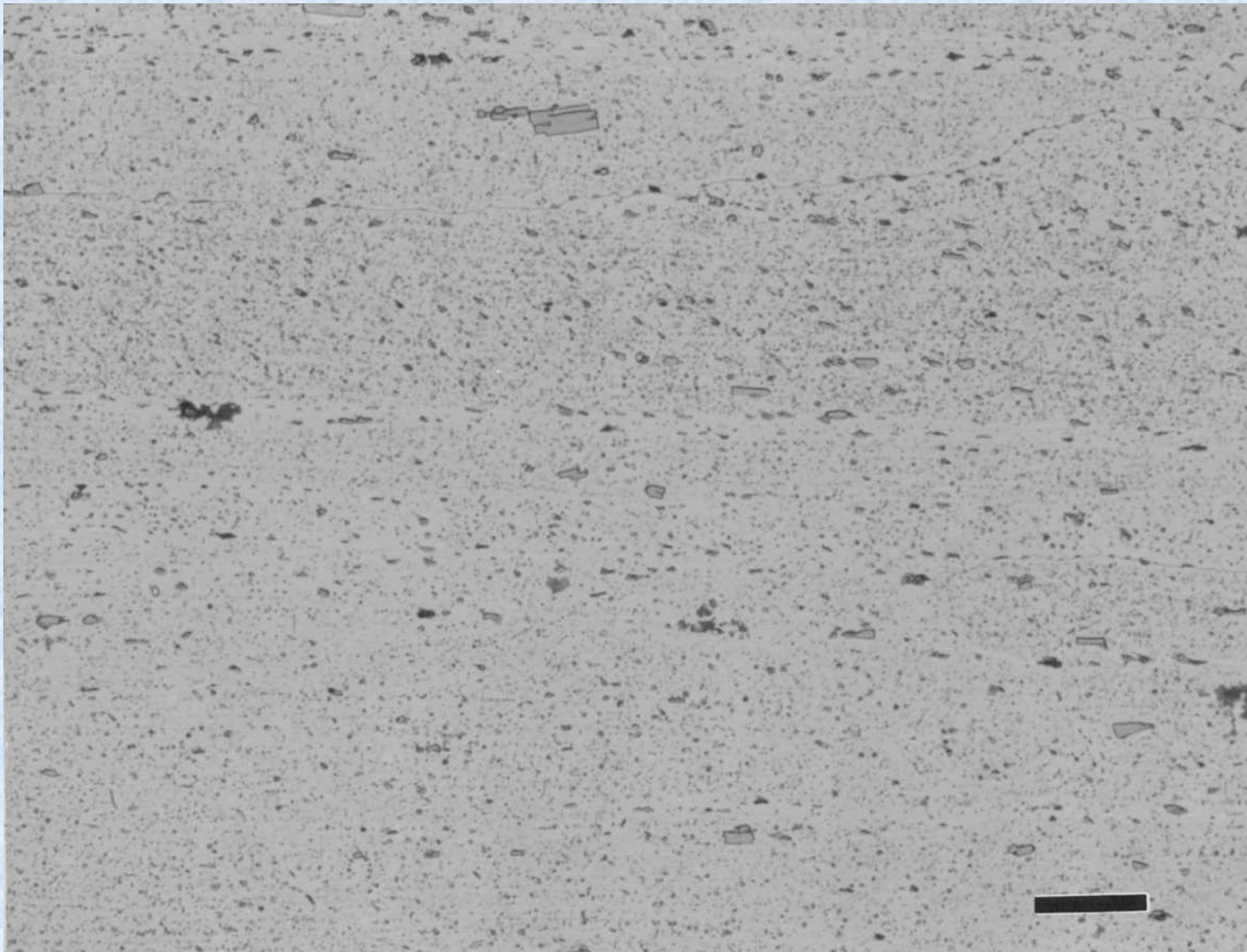
Graff-Sargent



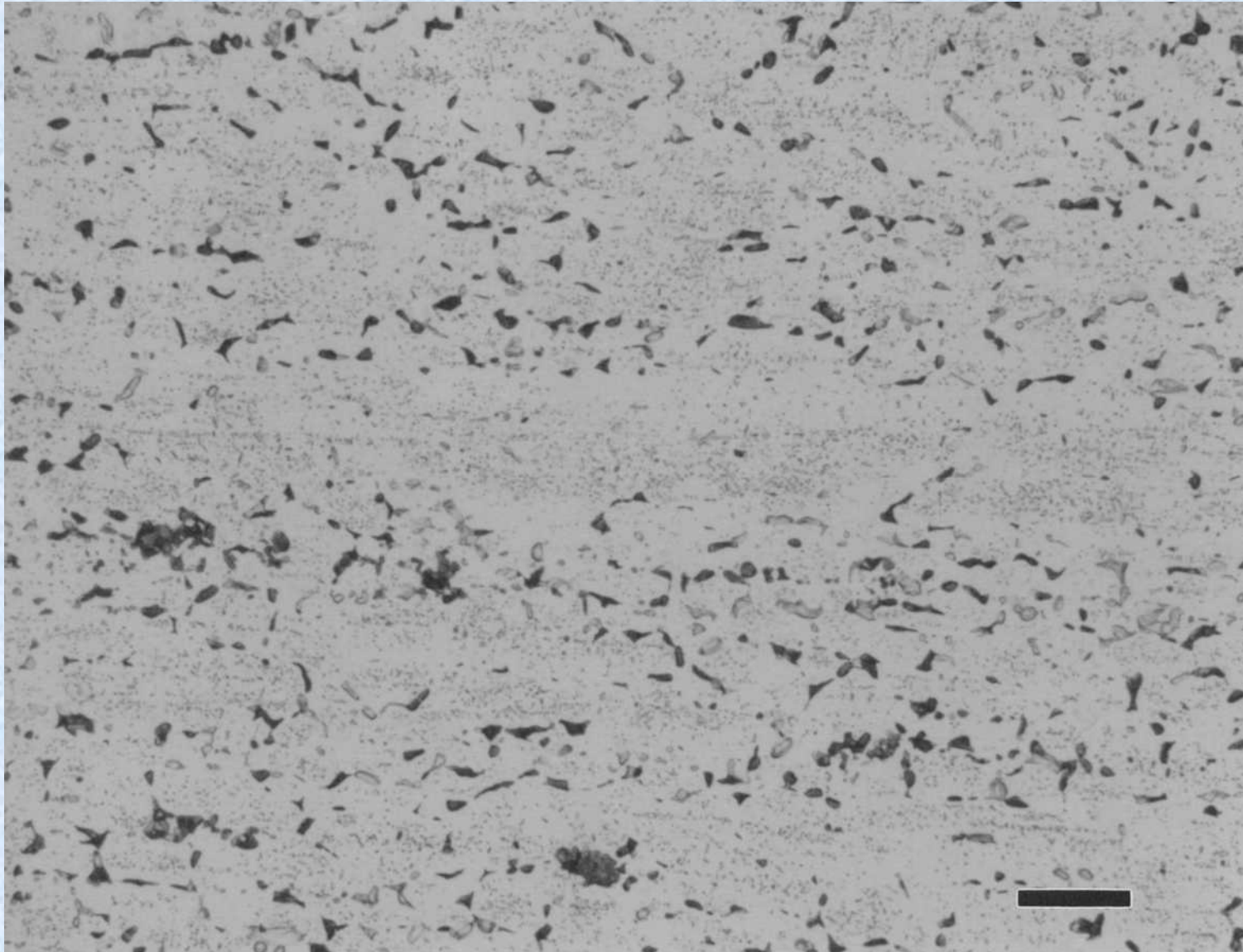
**Color is
200X**

Weck's

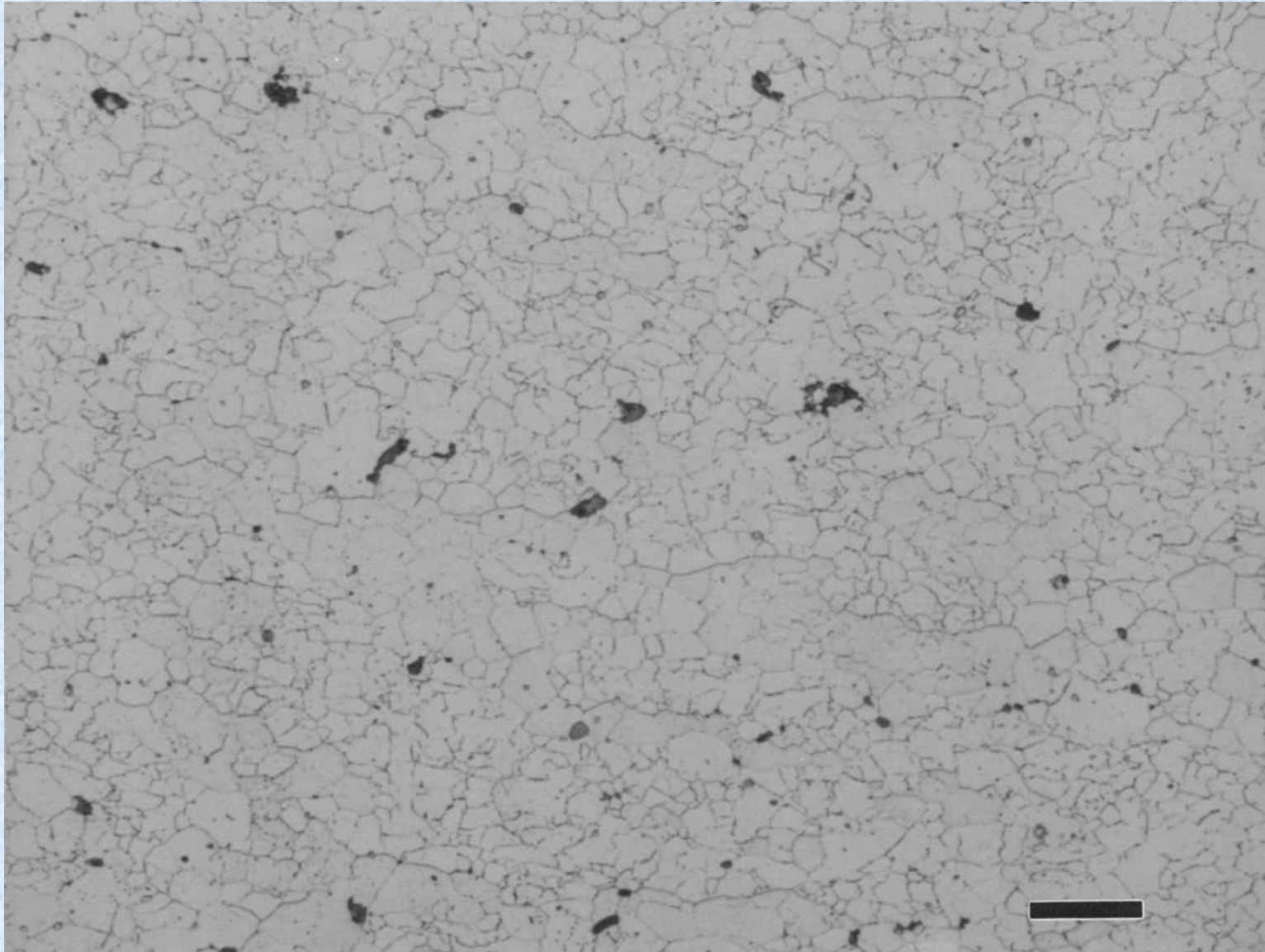




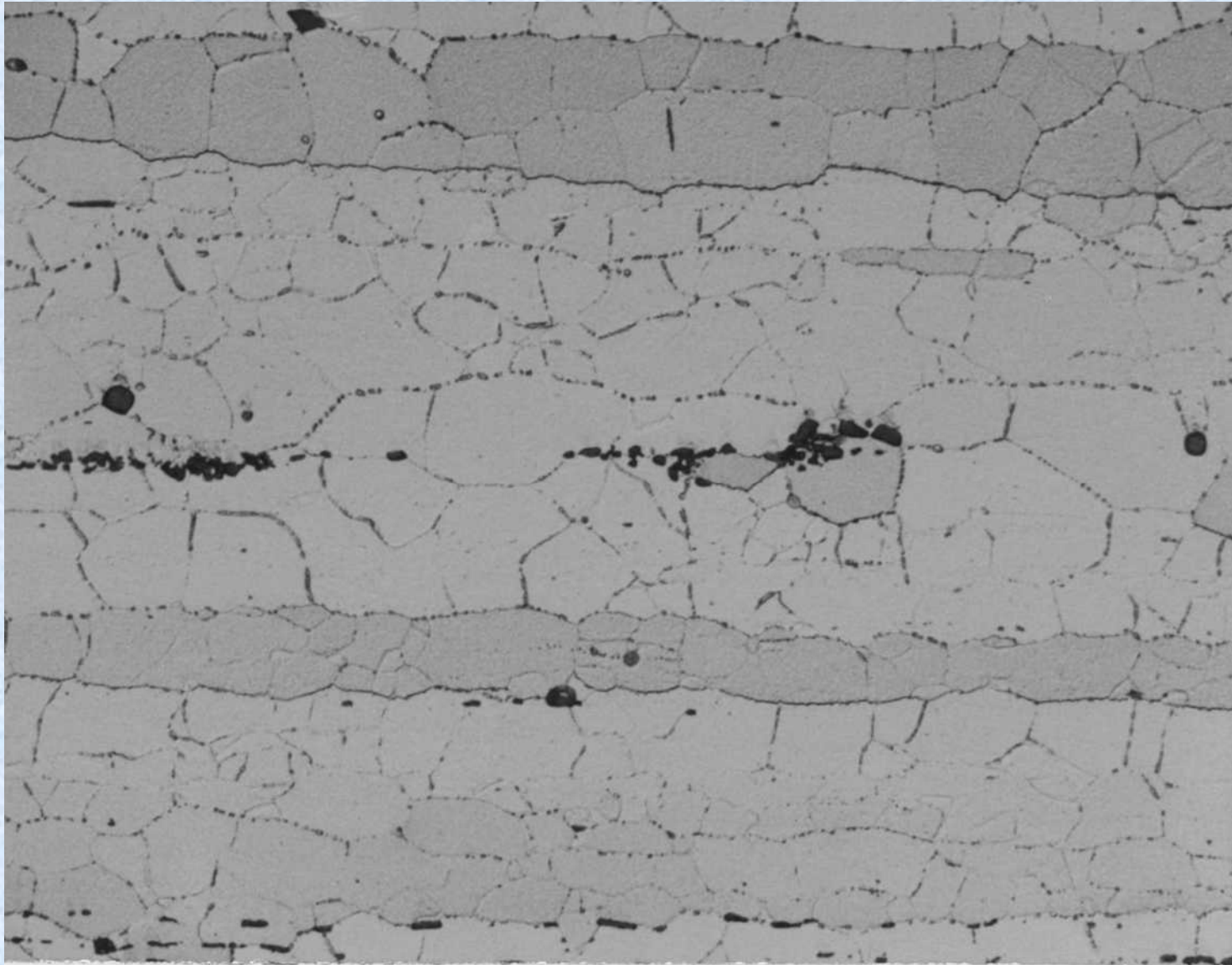
Wrought 7021-O annealed aluminum strip (Al – 1.5% Mg – 5.5% Zn – 0.12% Zr) etched with aqueous 0.5% HF. Magnification bar is 20 μm long.



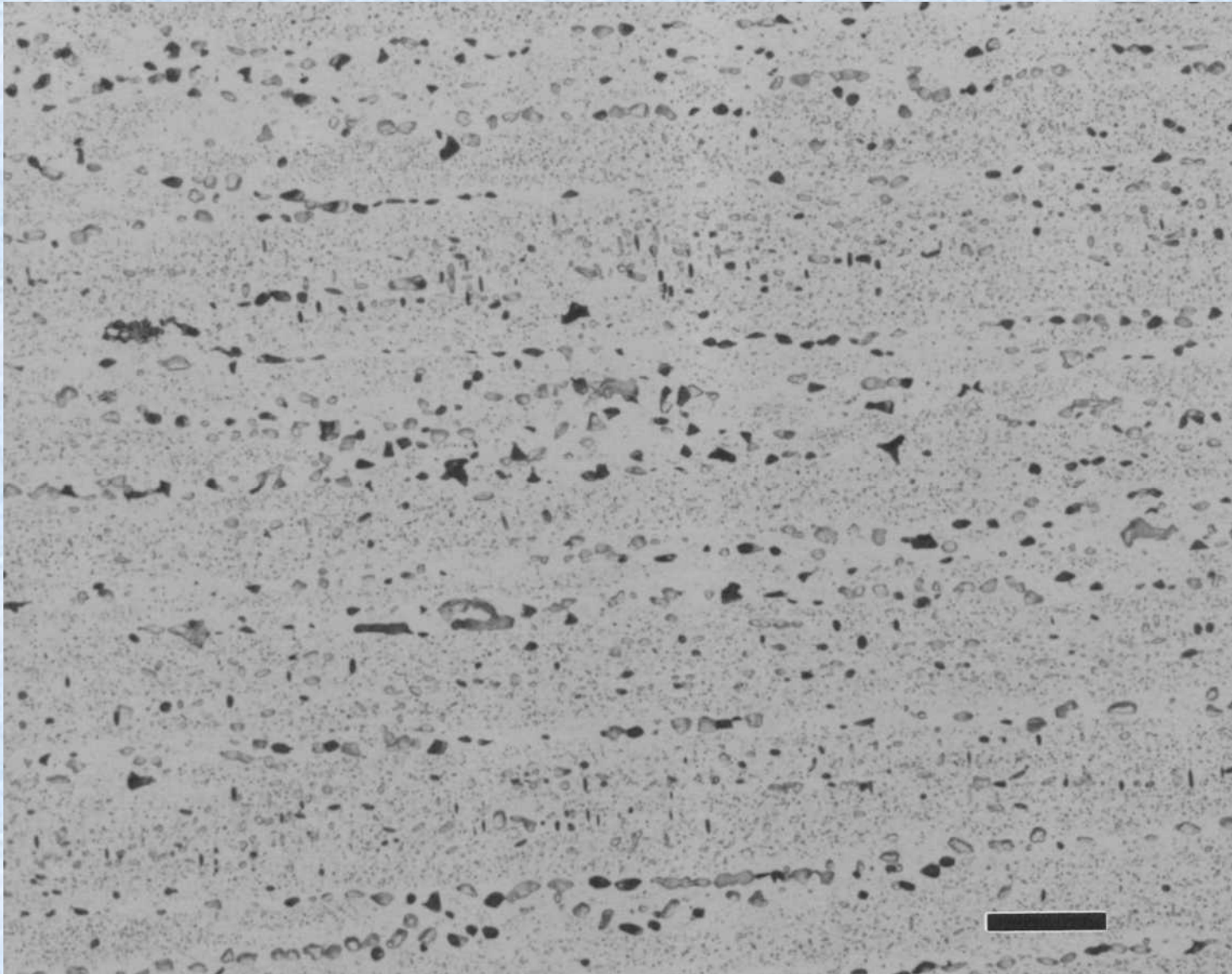
Wrought 7050 annealed aluminum (Al – 2.3% Cu – 2.3% Mg – 6.2% Zn – 0.12% Zr) etched with Keller's reagent to reveal the precipitates and coarse constituents. Annealing treatment: 426 °C (800 °F) – 3 h, cool slowly to 232 °C (450 °F), hold 6 h, air cool. Magnification bar is 20 μ m. 16 HRB.



Wrought 7050-T74 aluminum (Al – 2.3% Cu – 2.3% Mg – 6.2% Zn – 0.12% Zr) extrusion etched with Keller's reagent to reveal the grain structure and intermetallic precipitates. Magnification bar is 20 μm . 88 HRB.



Wrought 7050-T73 aluminum (Al – 2.3% Cu – 2.3% Mg – 6.2% Zn – 0.12% Zr) forging etched with Keller's reagent to reveal the grain structure and precipitates. Magnification bar is 20 μm .



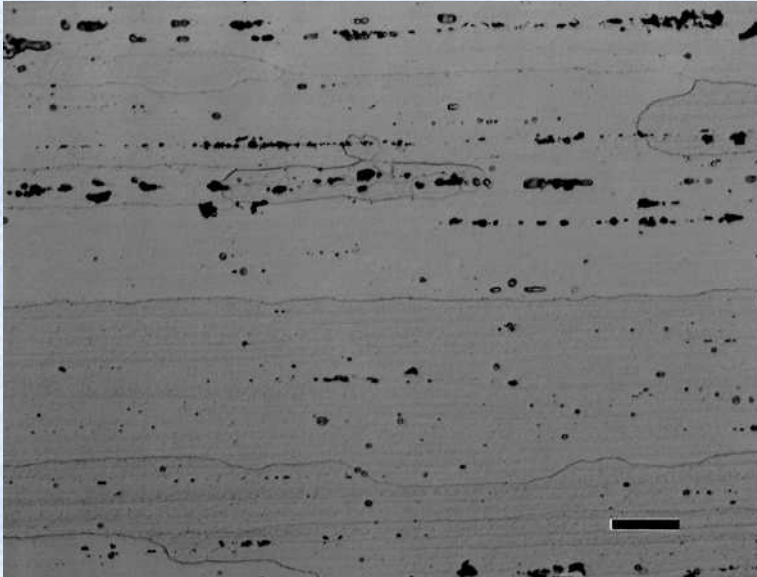
Wrought 7075 annealed aluminum (Al – 1.6% Cu – 2.5% Mg – 5.6% Zn – 0.23% Cr) etched with Keller's reagent to reveal the intermetallic precipitates. Annealing treatment: 426 °C (800 °F) – 3 h, cool slowly to 232 °C (450 °F), hold 6 h, air cool. Magnification bar is 20 μ m. 18 HRB.



Wrought 7075-T74 aluminum (Al – 1.6% Cu – 2.5% Mg – 5.6% Zn – 0.23% Cr) anodized with Barker's reagent (20 V dc, 2 min.) showing highly elongated, recrystallized surface grains on a fine grained interior structure. Magnification bar is 50 μm long. Viewed with crossed polarized light plus sensitive tint.

7075-T651

Keller's

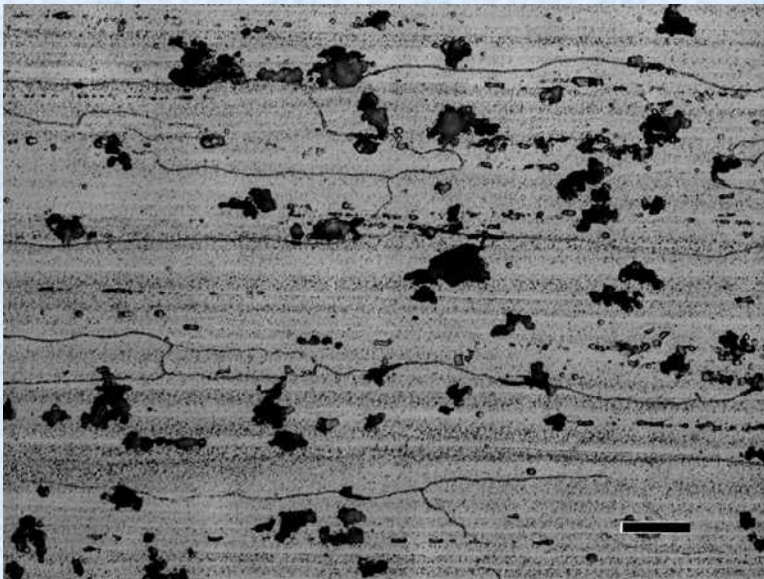


B&W –
Bars are
20- μ m long
500X

NaF-NaOH

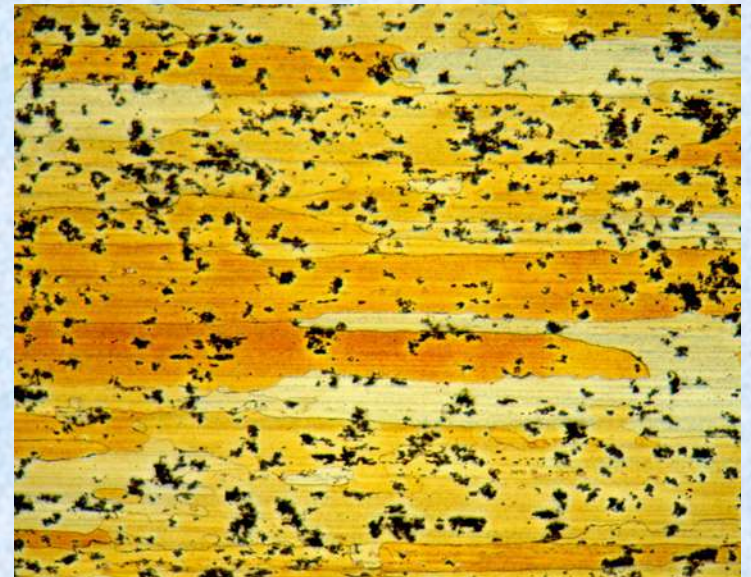


Graff-Sargent

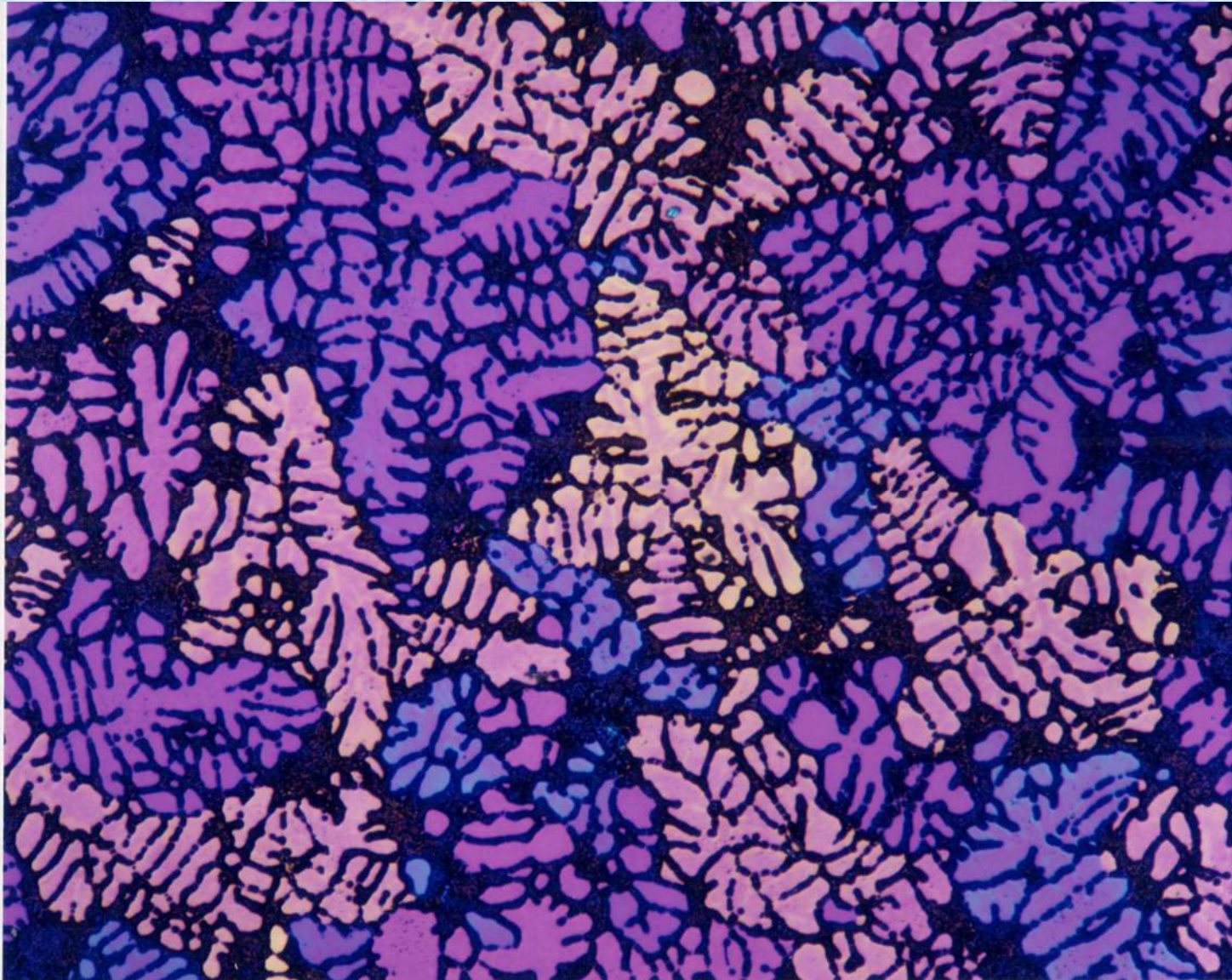


Color is
200X

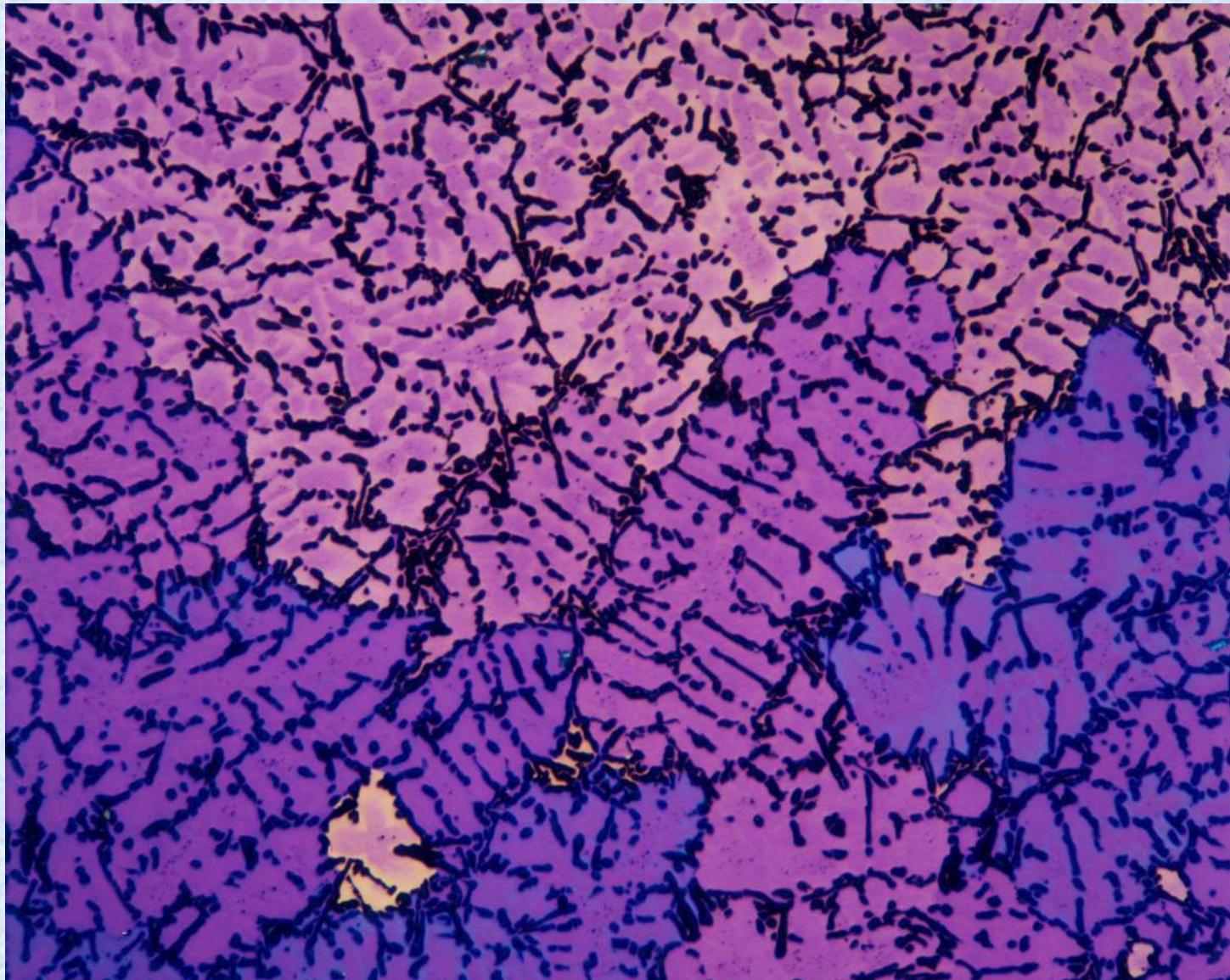
Weck's



Cast Alloys



As-cast A356 aluminum (Al – 7% Si – 0.3% Mg – <0.2% Fe) casting made by permanent molding. Anodized with Barker's reagent (30 V dc, 2 min.) and viewed with crossed polars + sensitive tint. Original at 50X. Note dendritic solidification pattern.

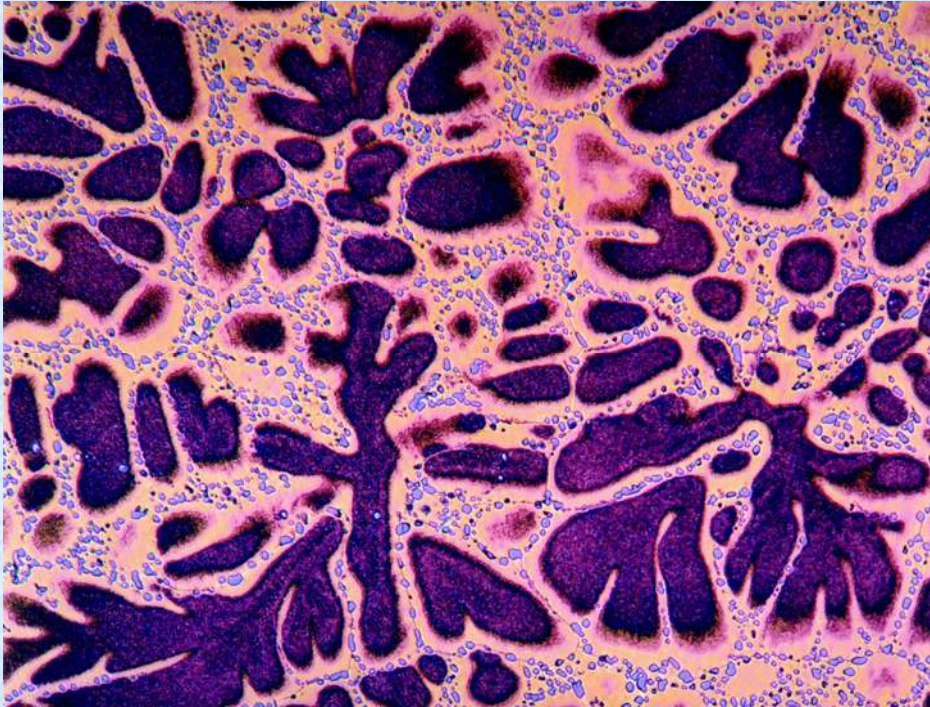


As-cast A356 aluminum (Al – 7% Si – 0.3% Mg -<0.2% Fe) casting made by sand casting. Anodized with Barker's reagent (30 V dc, 2 min.) and viewed with crossed polarized light plus sensitive tint. Original at 50X. Note dendritic solidification pattern.

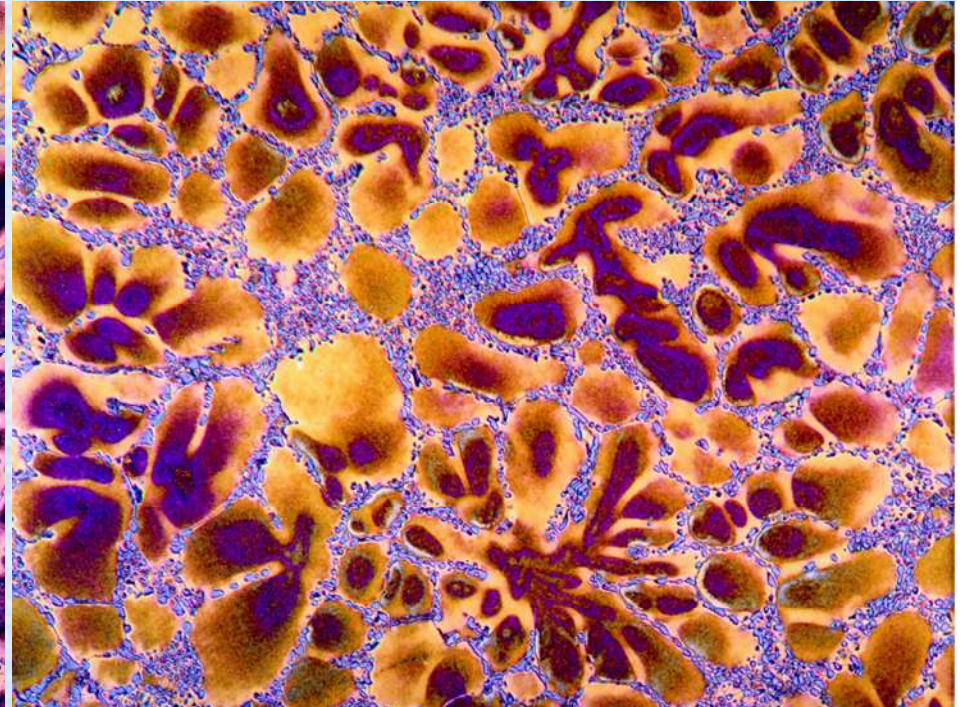


As-cast A356 aluminum (Al – 7% Si – 0.3% Mg – <0.2% Fe) etched with Keller’s reagent. Magnification bar is 20 μm long.

Cast A356 Aluminum



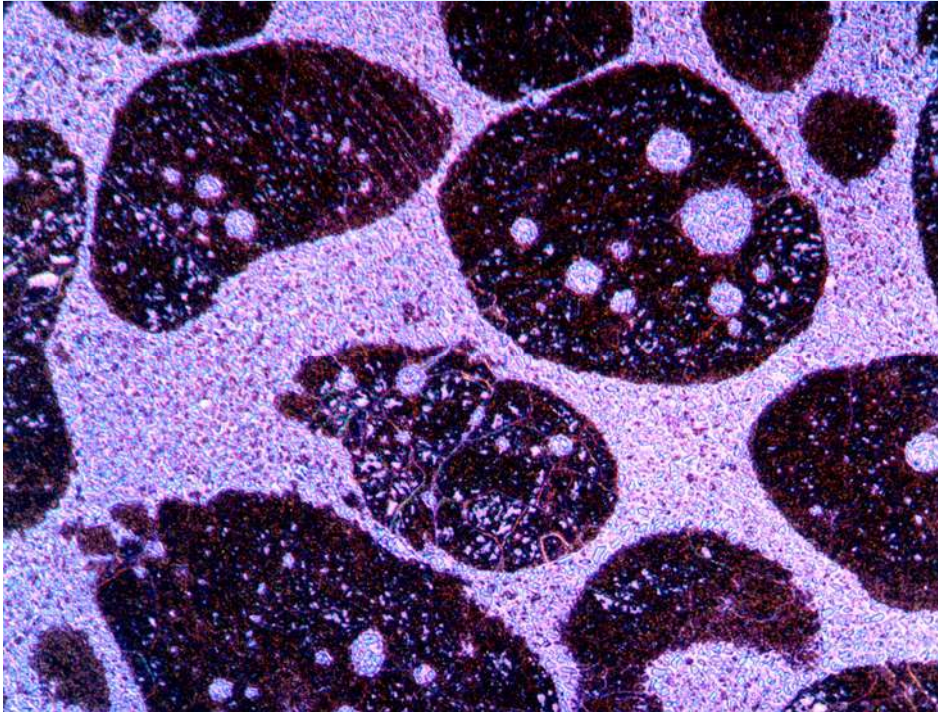
Small Permanent Mold Casting, 200X



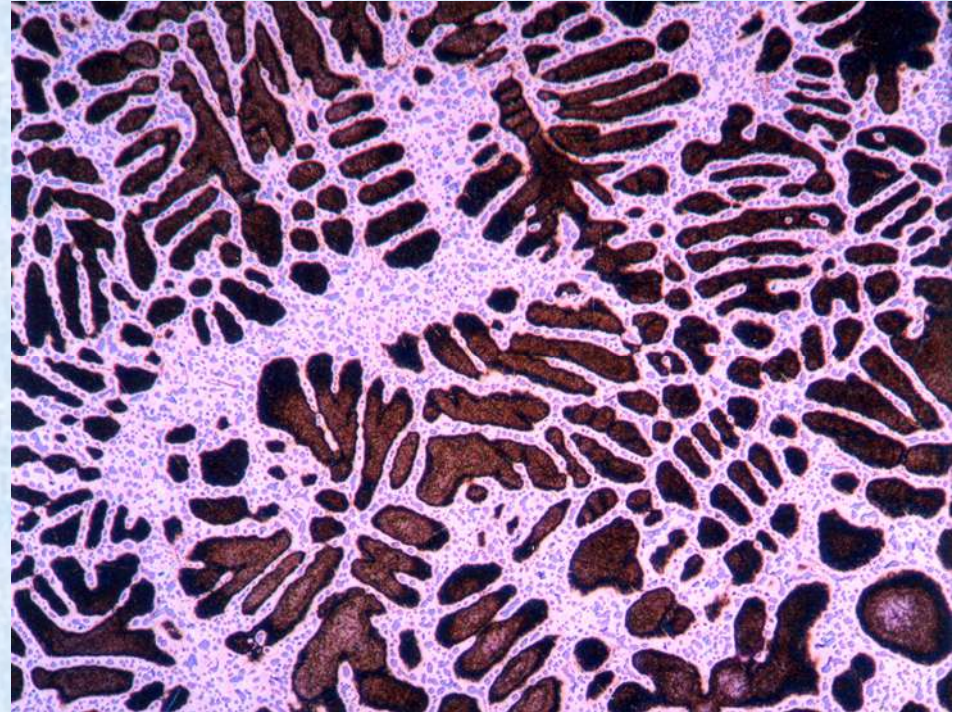
Large Permanent Mold Casting, 200X

Dendritic structure and eutectic structure of A356 permanent mold castings revealed using Weck's reagent (polarized light plus sensitive tint, 200X)

Cast A356 Aluminum

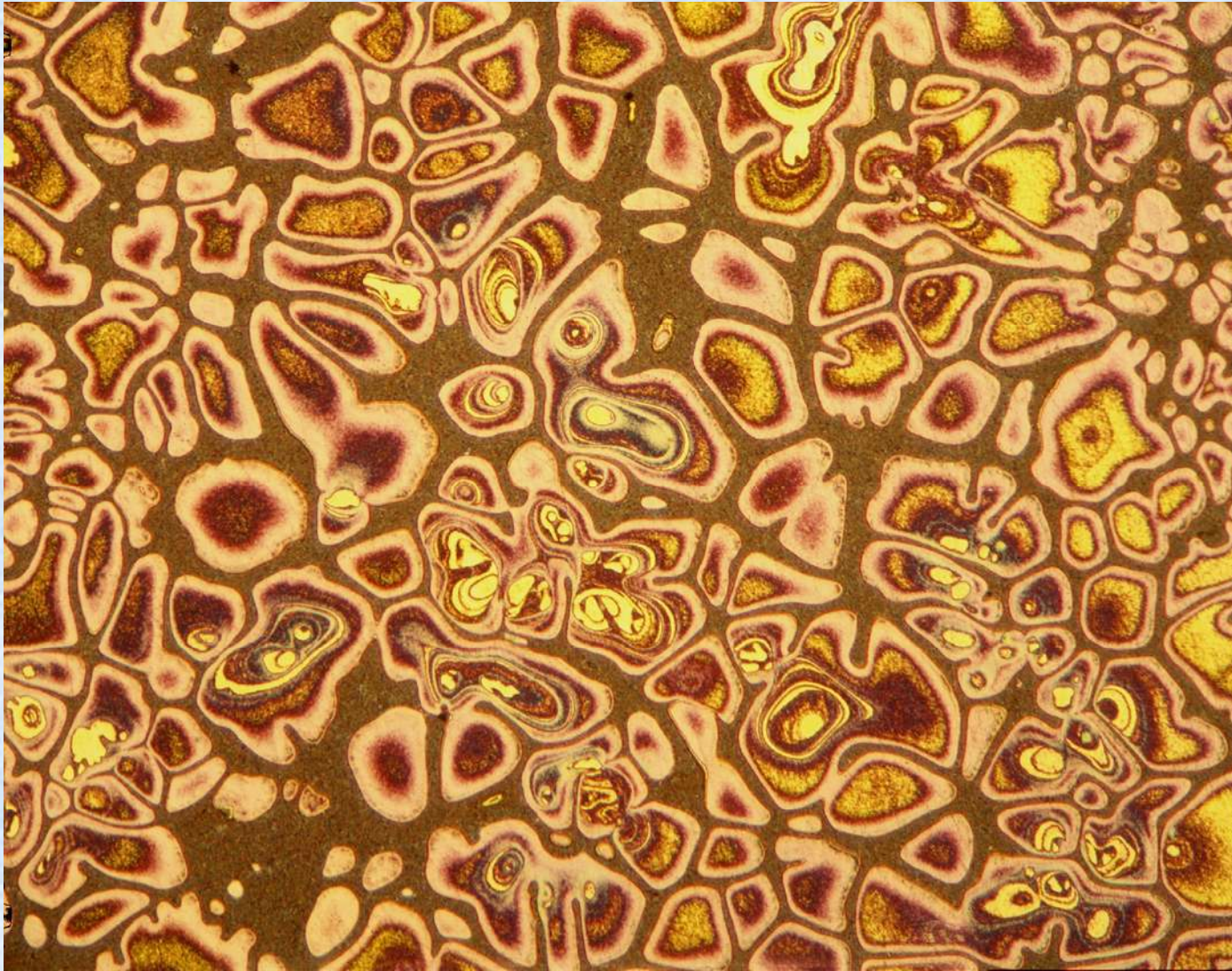


Thixocast, 200X

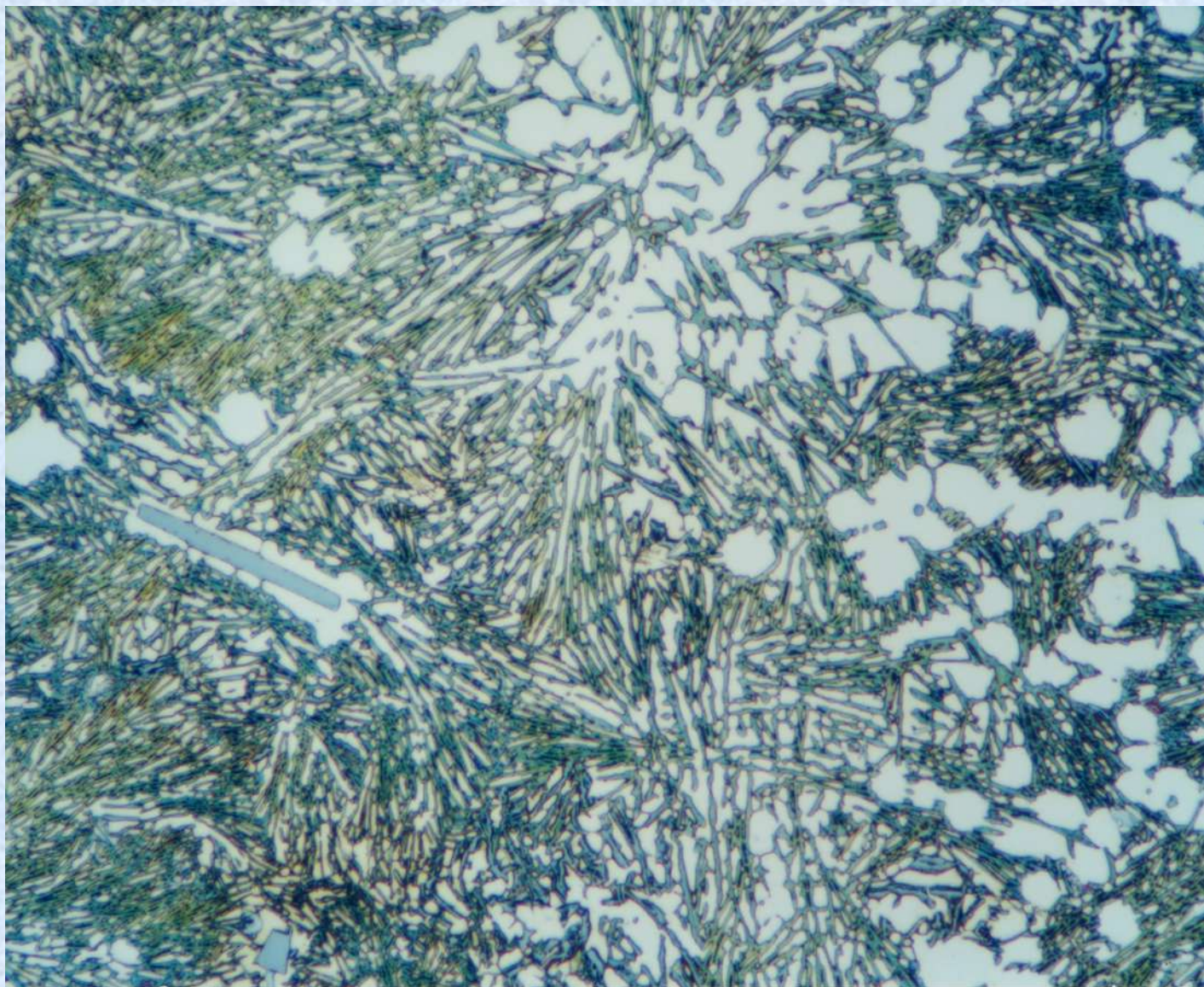


Thixocast and Thixoformed

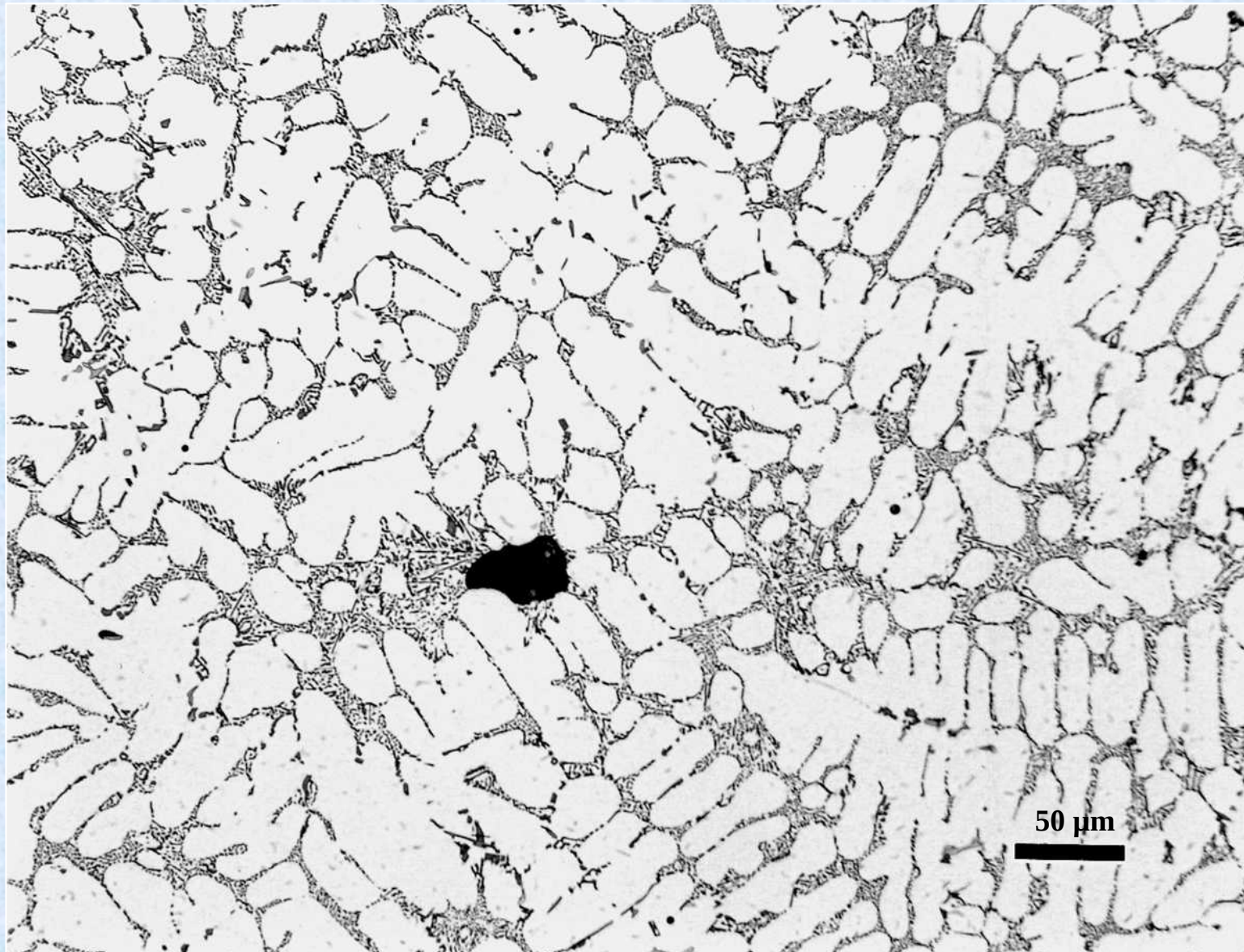
Microstructure of A356 made by thixocasting and by thixocasting and thixoforming revealed using Weck's reagent (viewed with polarized light and sensitive tint, 200X).



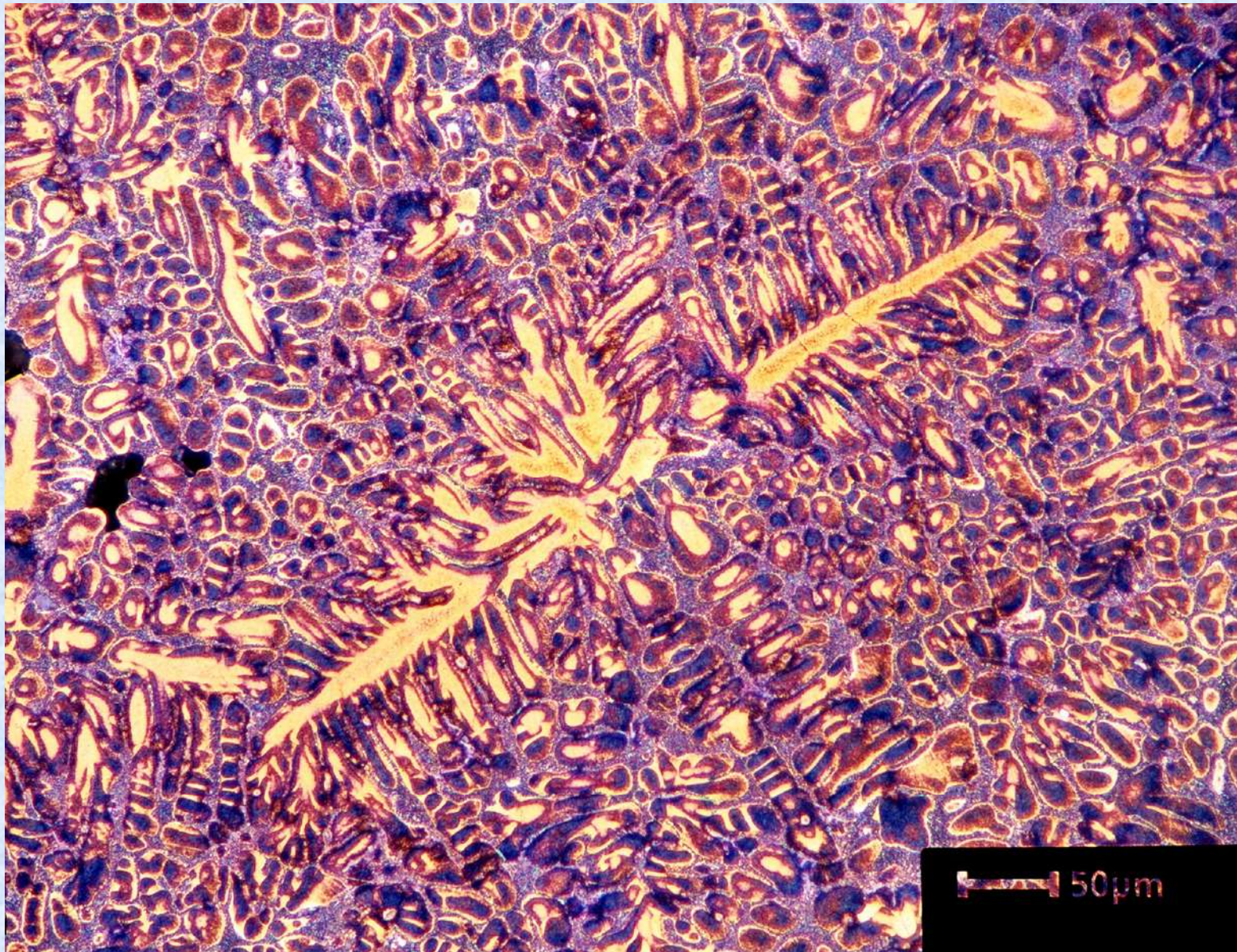
Microstructure of an SSM billet of A357 aluminum etched with Weck's and viewed in bright field (200x).



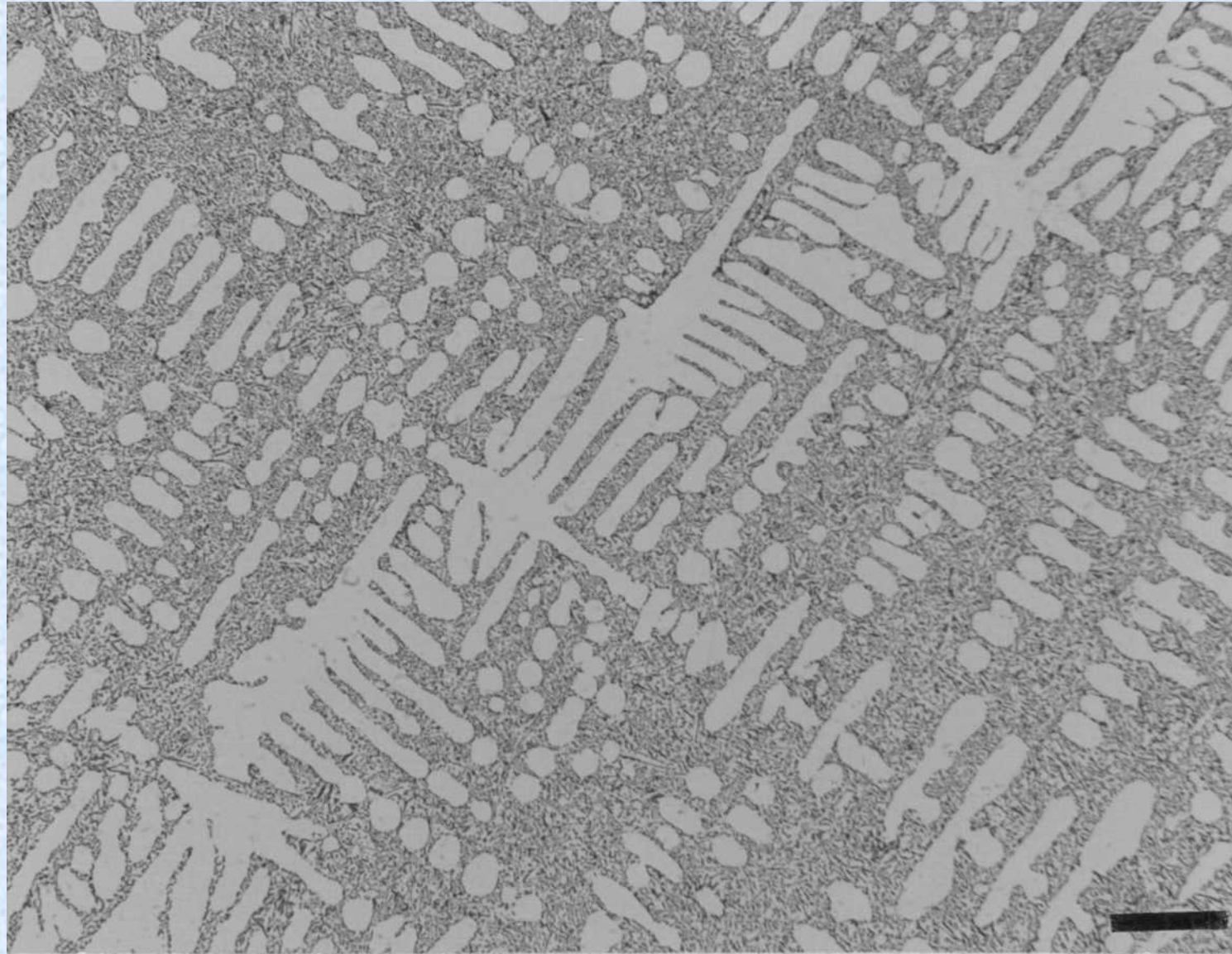
As-cast Al – 11.6% Si – 0.6% Fe tint etched with Weck's reagent and viewed with crossed polars. Original at 100X.



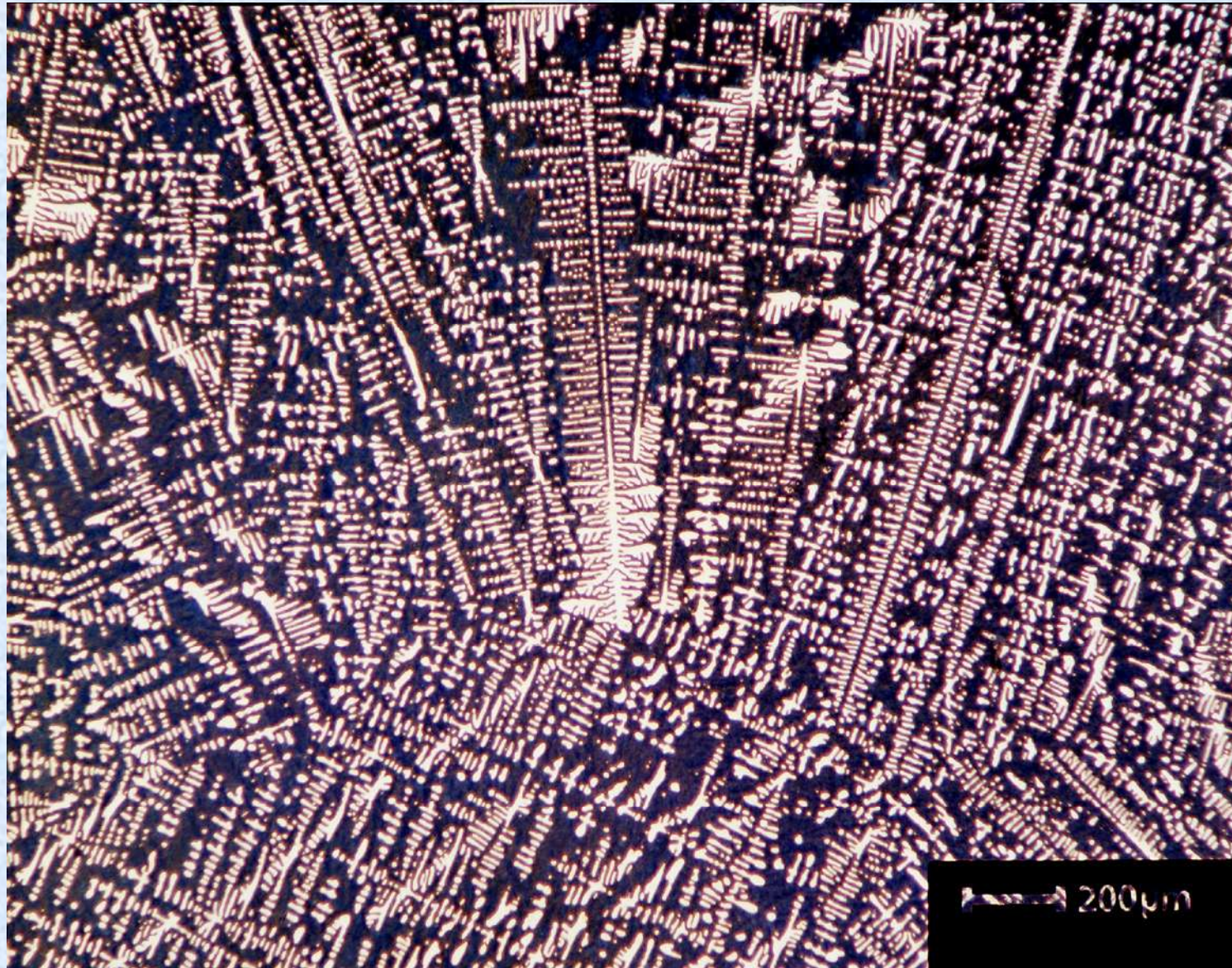
Hypoeutectic Al – 7.15% Si microstructure of primary α -Al and a eutectic of α -Al + Si (0.5% HF etch).



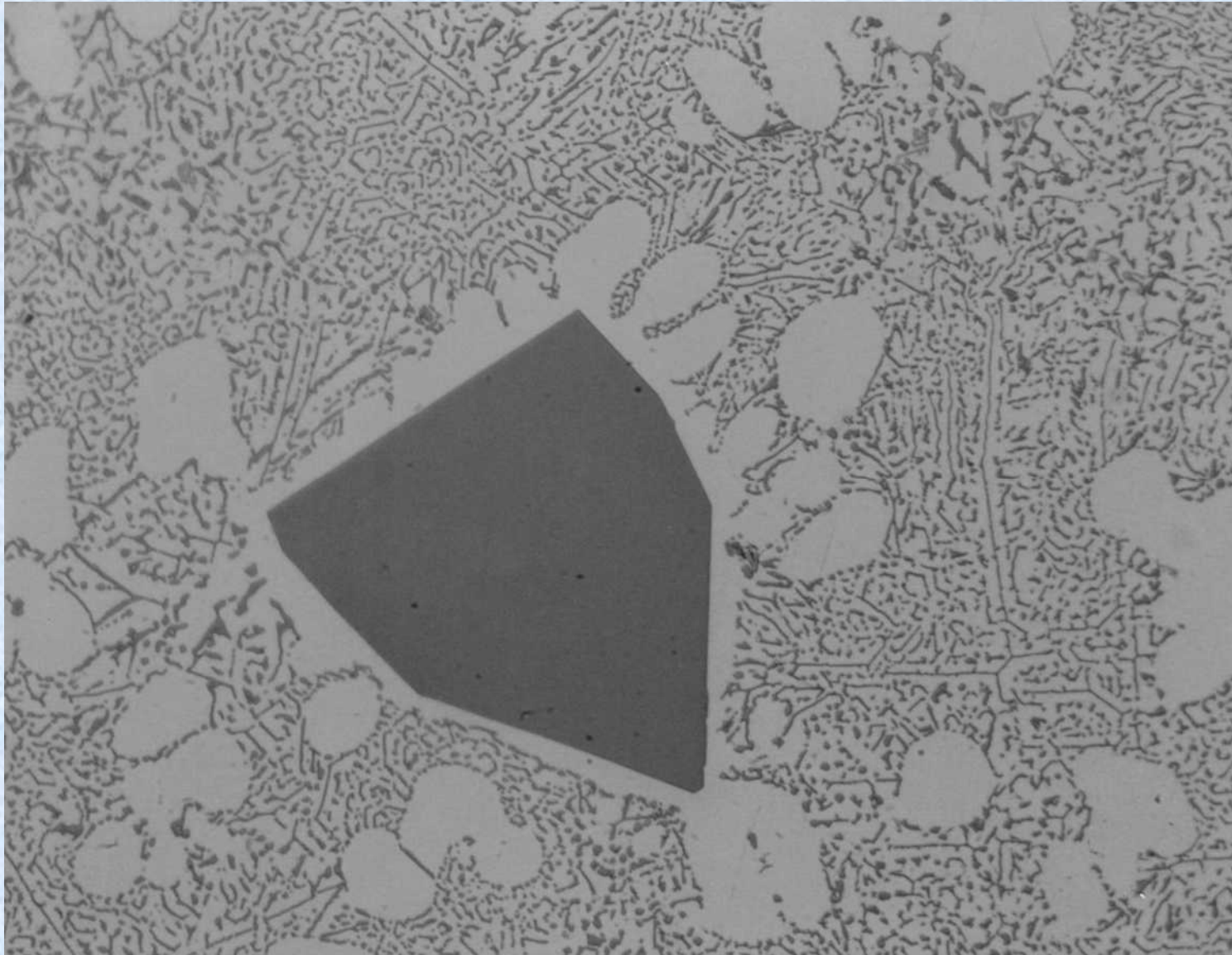
Dendrites of α -Al and a eutectic of α -Al and Si in as-cast Al – 7.12% Si etched with Weck's, polarized light plus sensitive tint.



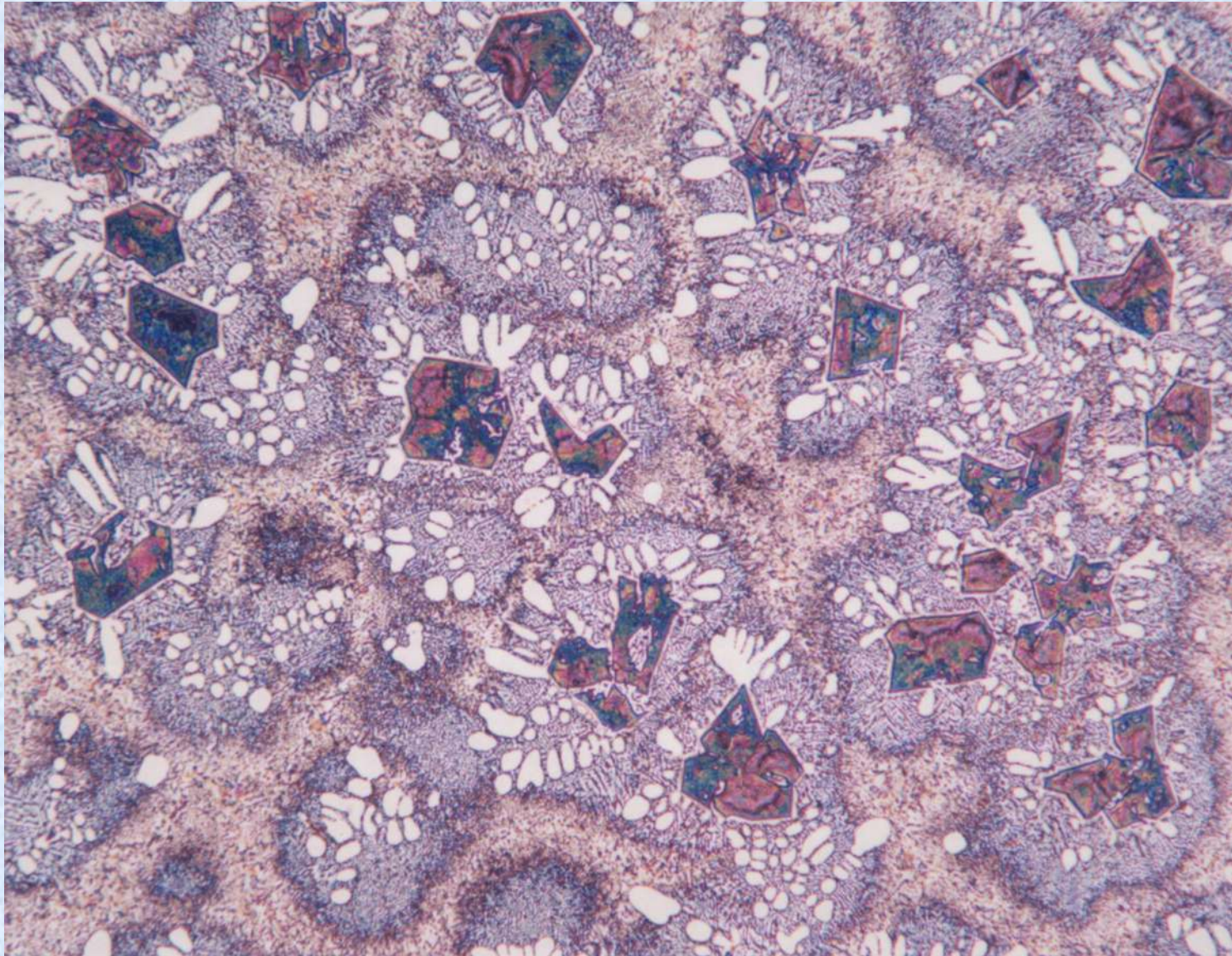
As-cast hypoeutectic Al – 11.8% Si showing alpha dendrites and an alpha-Si eutectic. Etched with aqueous 0.5% HF. Magnification bar is 50 μm long.



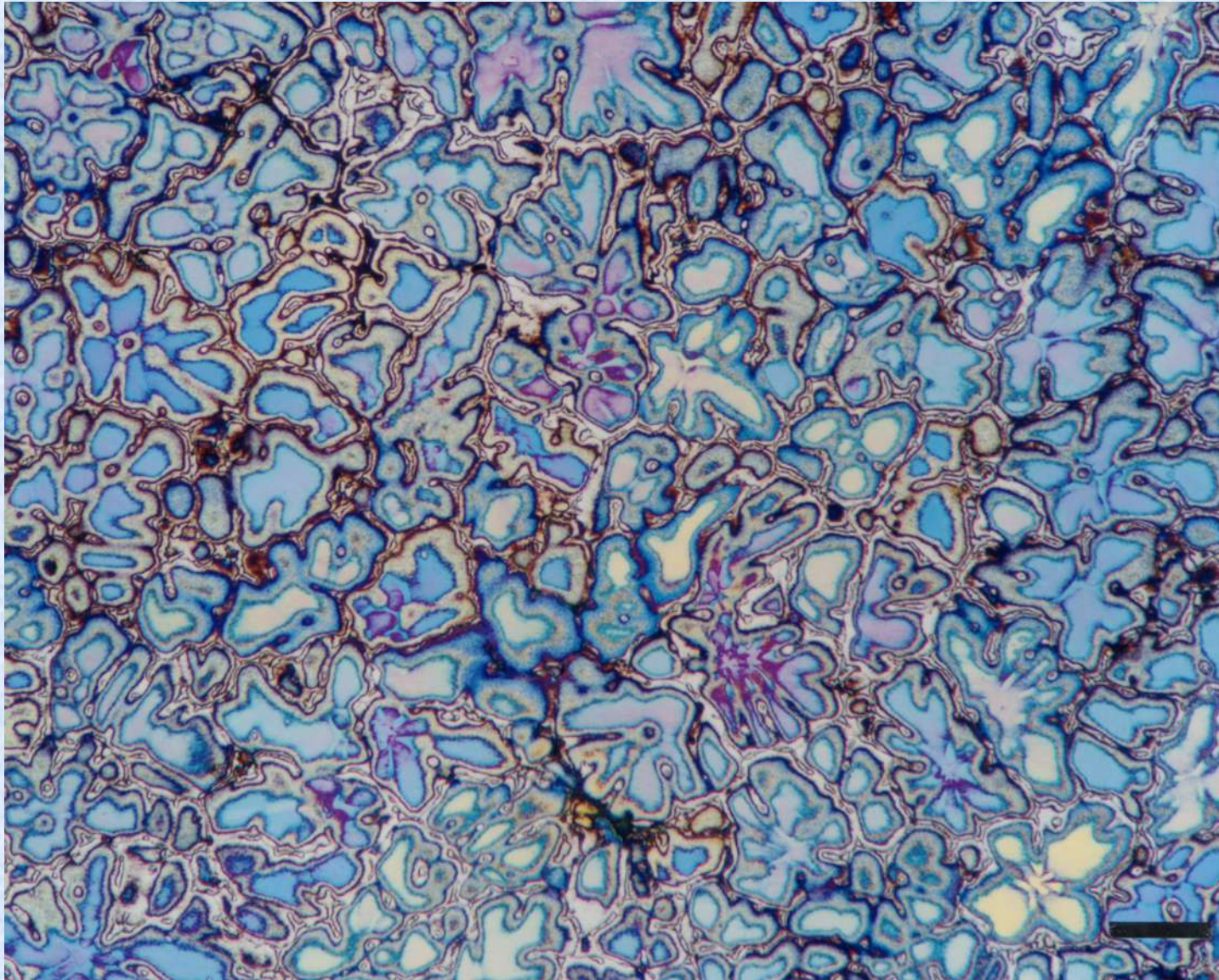
Near-eutectic microstructure of as-cast Al – 11.7% Si alloy etched with Weck's and viewed with polarized light plus sensitive tint.



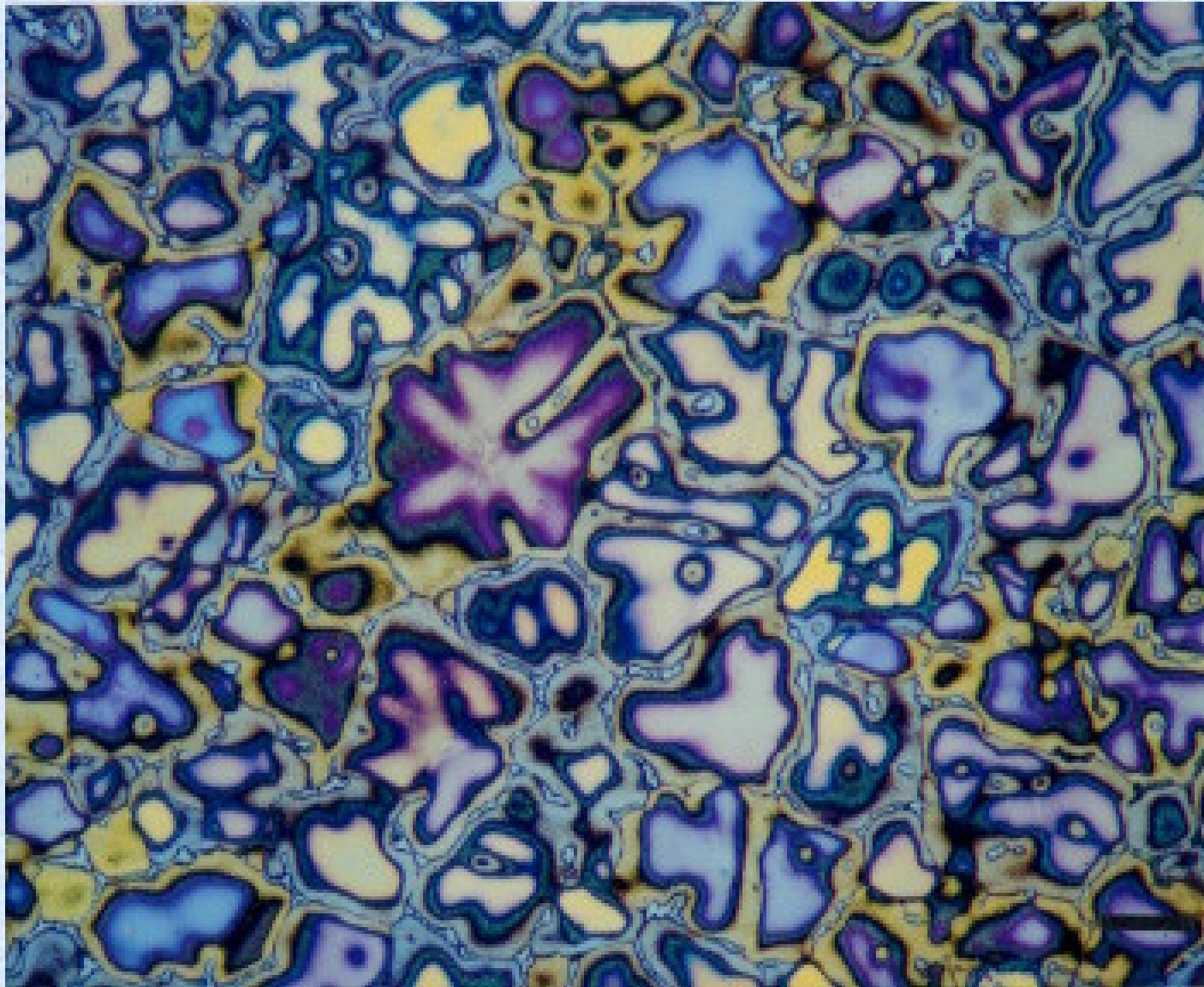
As-cast hypereutectic Al – 19.85% Si showing primary hypereutectic Si particles surrounded by a matrix of the alpha-Si eutectic. Etched with aqueous 0.5% HF. Original at 500X.



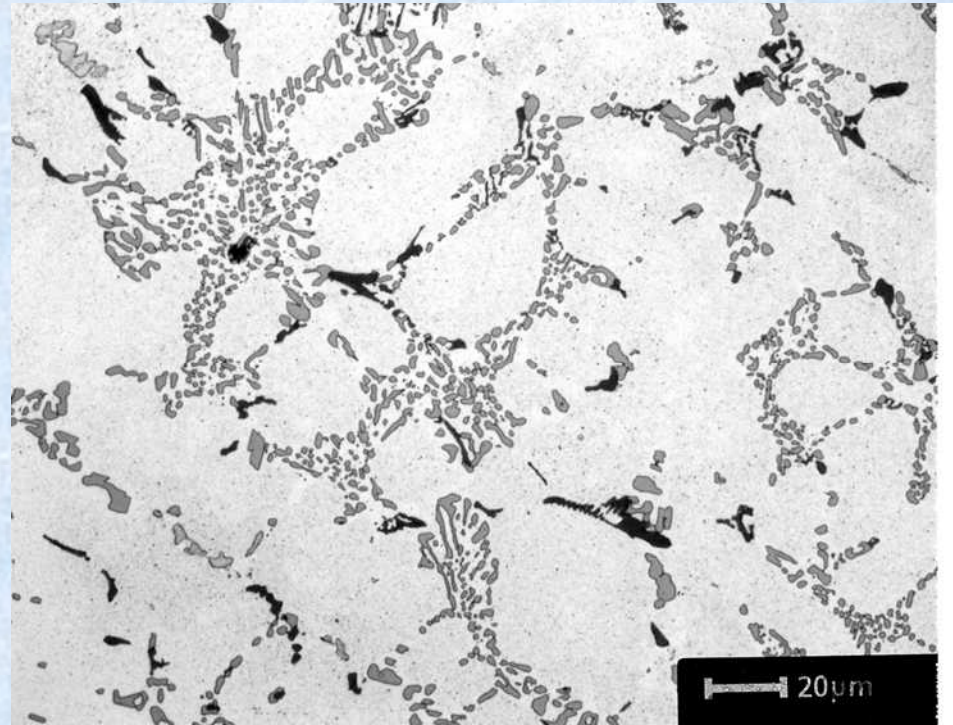
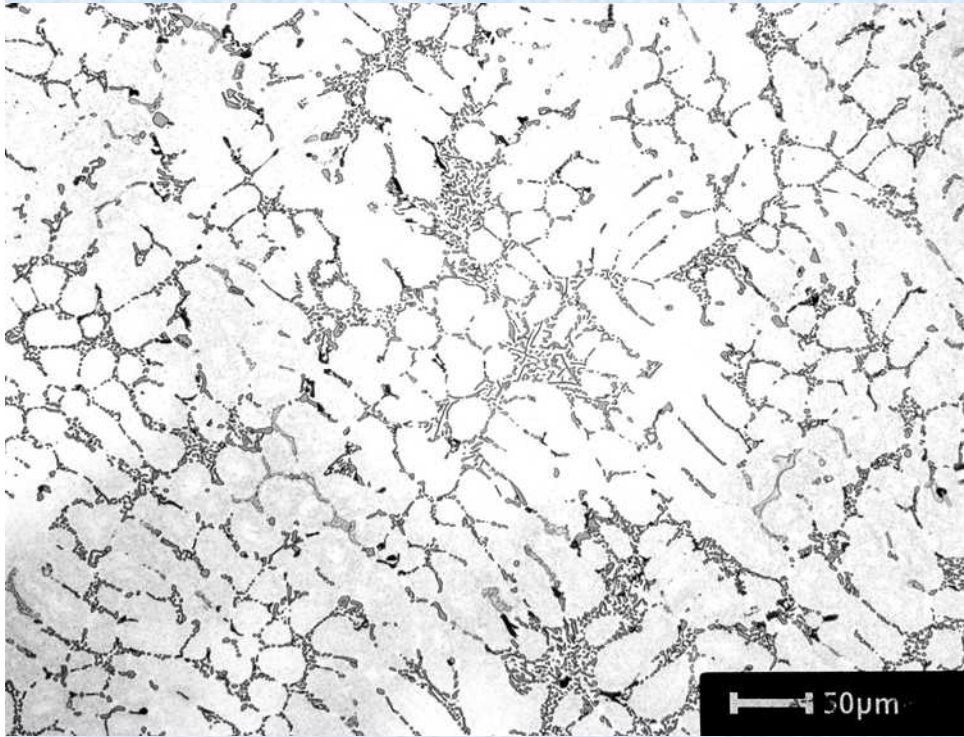
As-cast hypereutectic Al – 19.85% Si showing primary hypereutectic Si particles surrounded by a matrix of the alpha-Si eutectic. Tint etched with Weck's reagent. Original at 200X



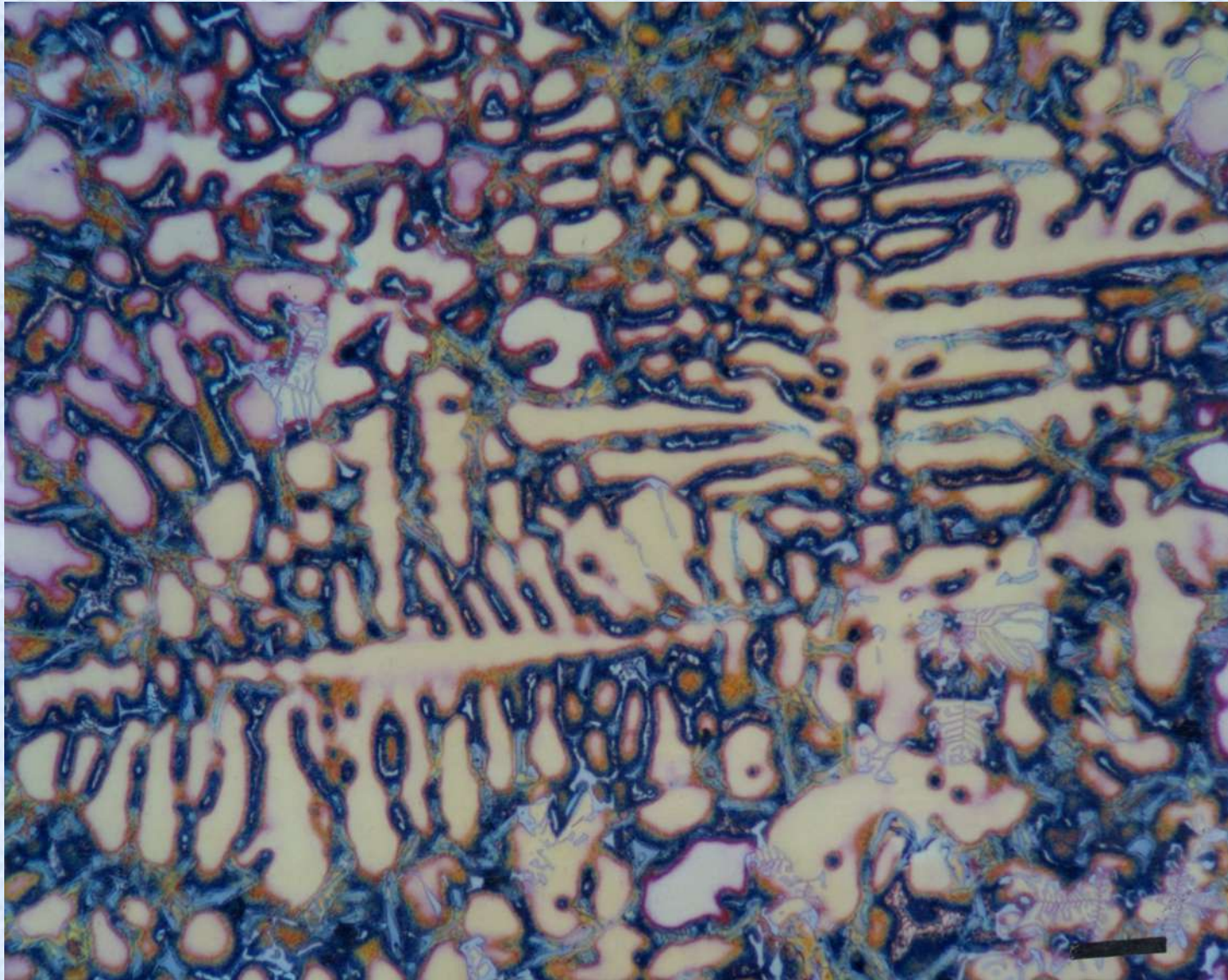
As-cast 201 aluminum (Al – 4.6% Cu – 0.3% Mg – 0.3% Mn) tint etched with Weck’s reagent and viewed with crossed polars. Magnification bar is 100 μ m long. Reveals segregation (“coring”) in the primary alpha dendrites.



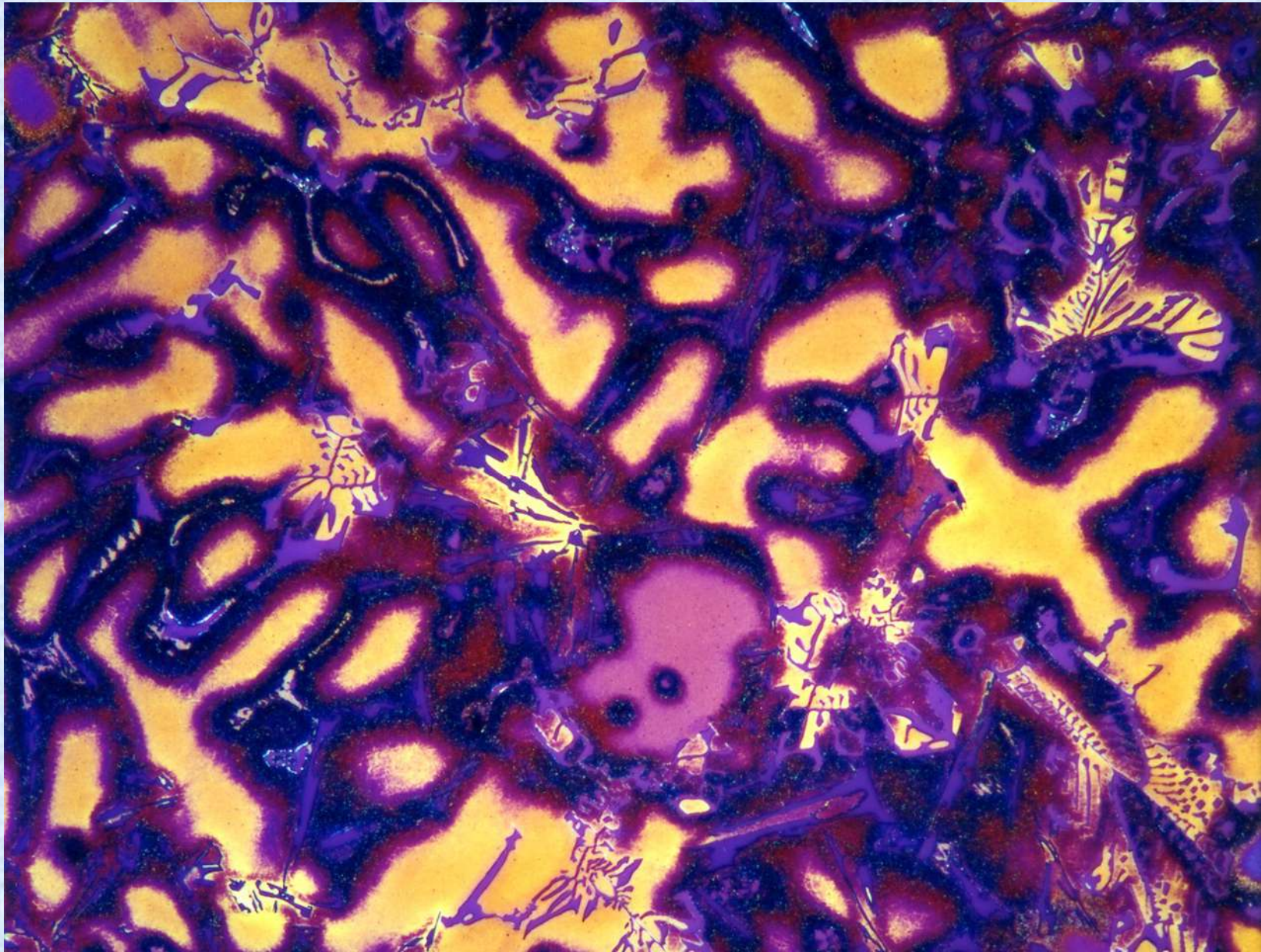
As-cast 206 aluminum (Al – 4.4% Cu – 0.3% Mg – 0.3% Mn) tint etched with Weck's reagent and viewed with crossed polars + sensitive tint. Magnification bar is 50 μ m long.



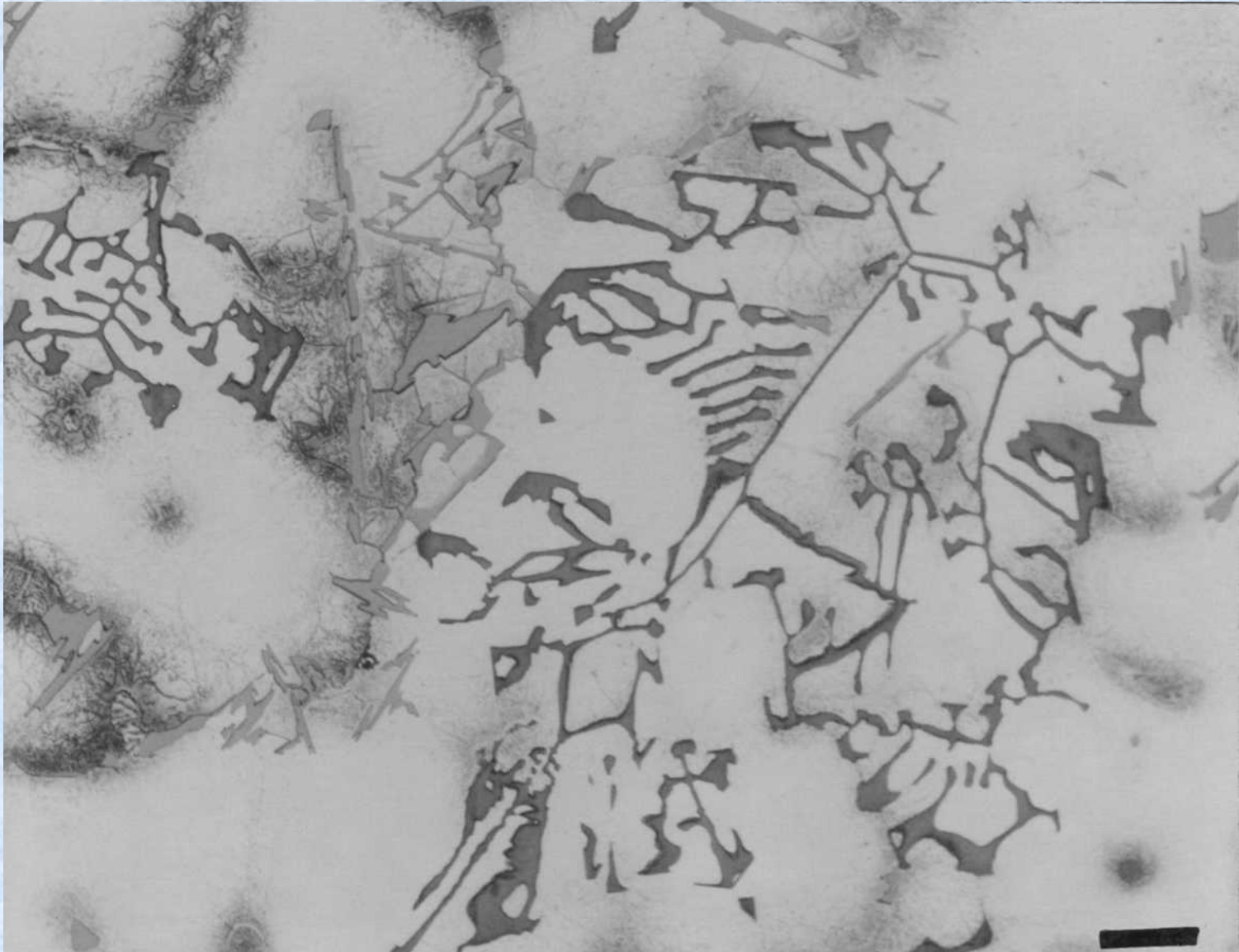
As-cast 319 aluminum (Al – 6.0% Si – 3.5% Cu) etched with Keller's reagent.



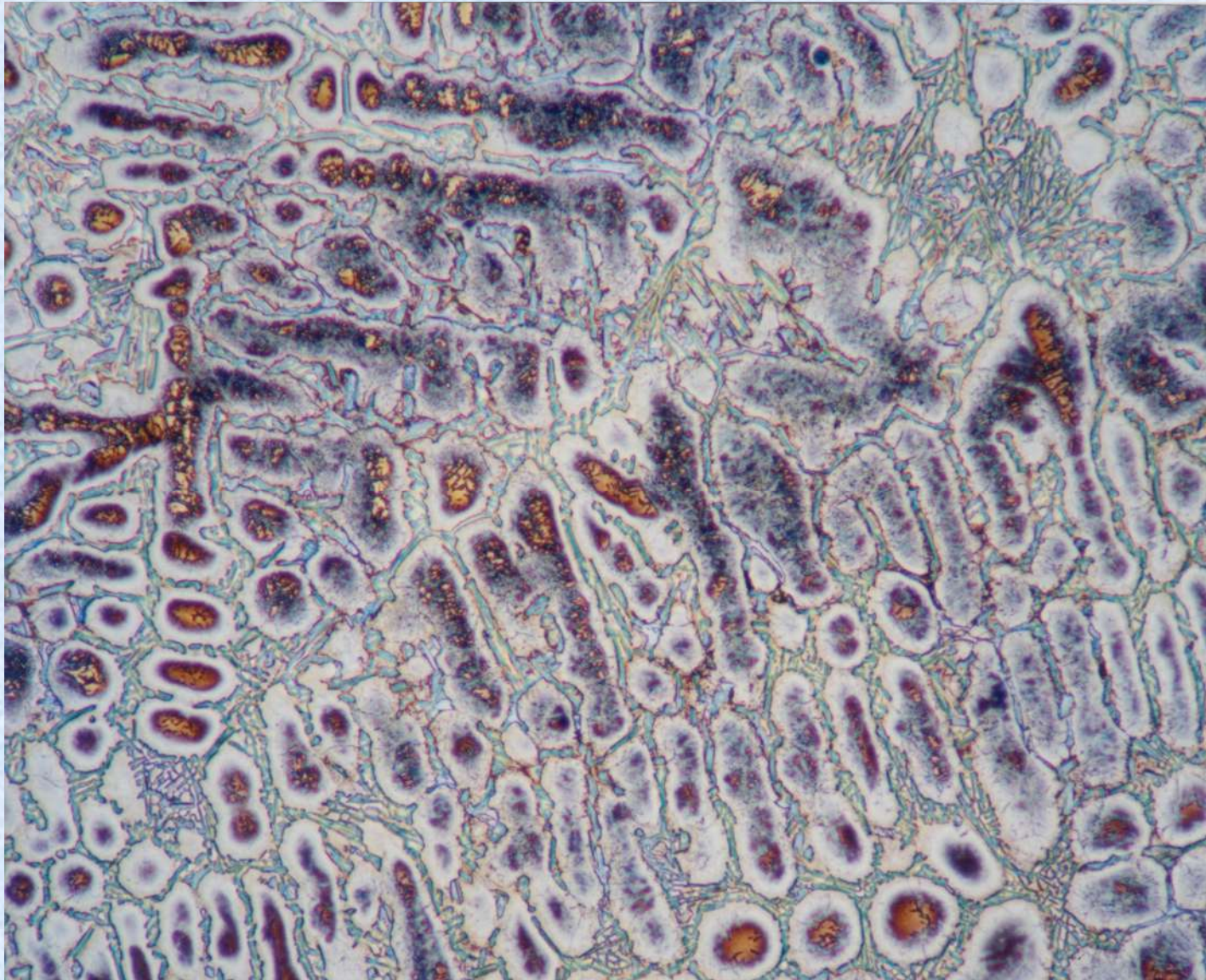
As-cast 319 aluminum (Al – 6.0% Si – 3.5% Cu) tint etched with Weck's reagent and viewed with crossed polarized light. Magnification bar is 100 μ m long.



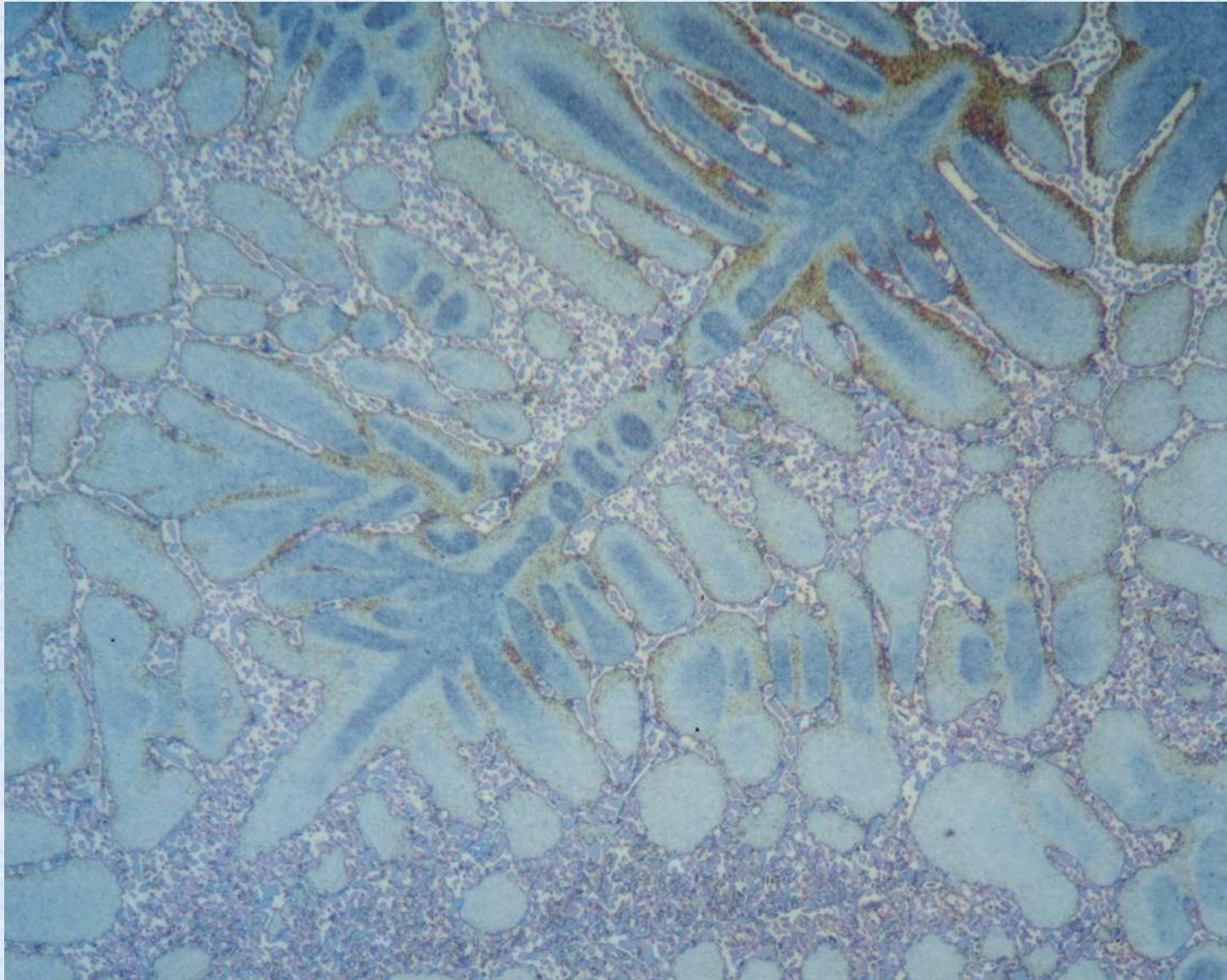
As-cast 319 aluminum (Al – 6.0% Si – 3.5% Cu) tint etched with Weck's reagent and viewed with crossed polarized light. Magnification bar is 100 μm long.



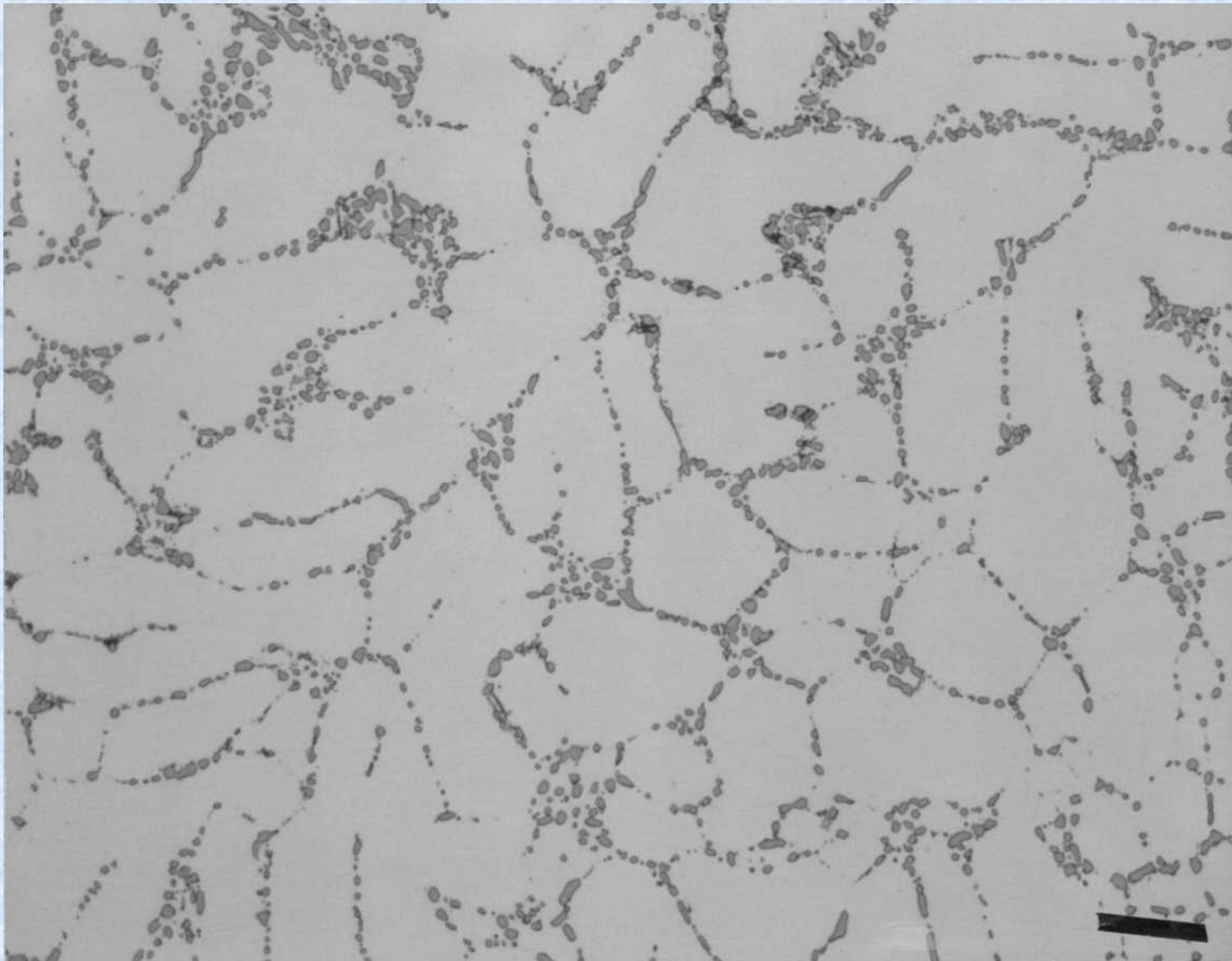
As-cast 319 aluminum (Al – 6.0% Si – 3.5% Cu) tint etched with Keller's reagent revealing the intermetallic precipitates. Magnification bar is 50 μm long.



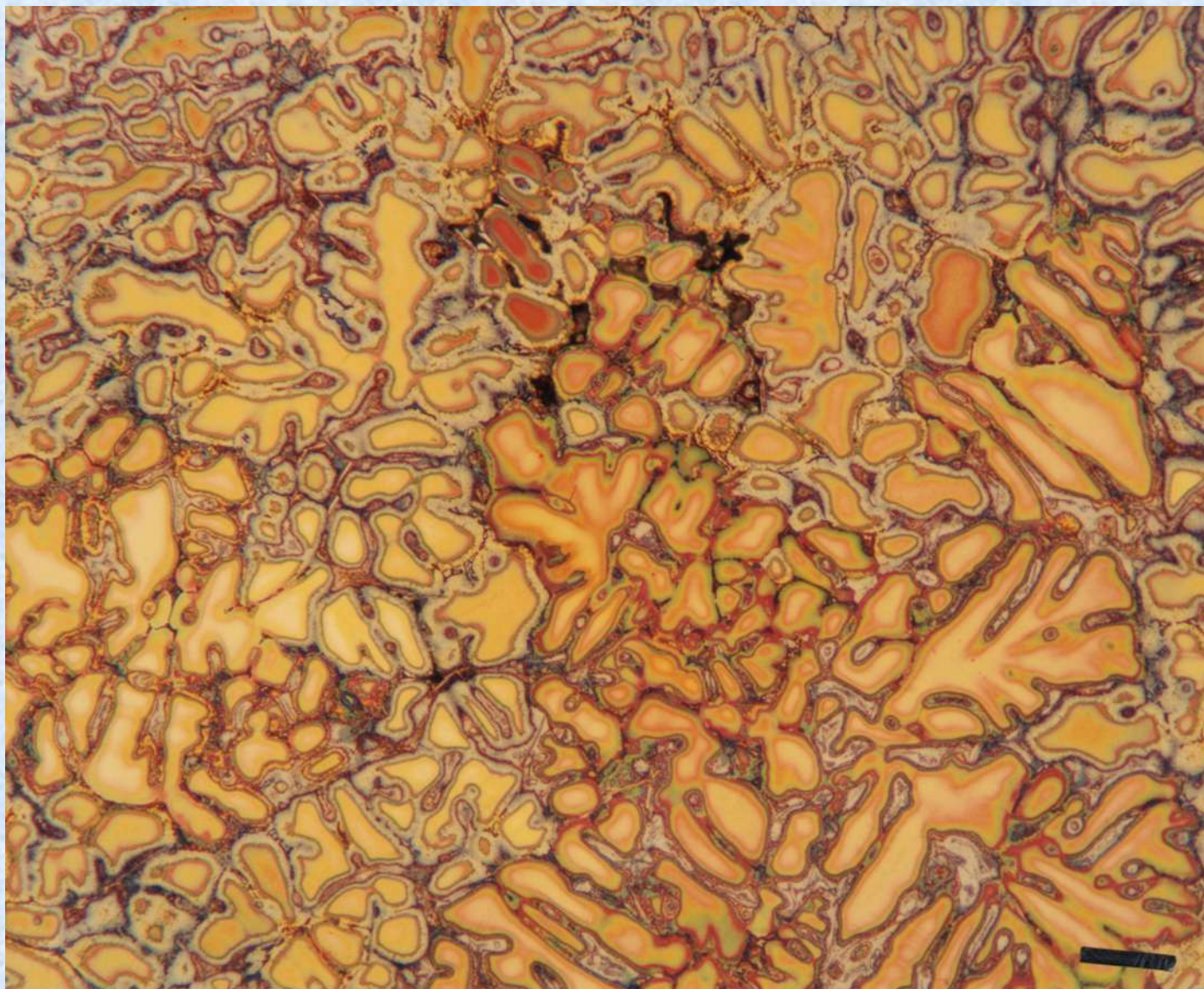
As-cast Al – 7.3% Si – 0.4% Mg tint etched with Weck's reagent and viewed with crossed polarized light plus sensitive tint. Original at 100X. Note coring segregation in the primary alpha dendrites.



As-cast A356 aluminum (Al – 7% Si – 0.3% Mg -<0.2% Fe) casting made by permanent molding tint etched with Weck's reagent and viewed with crossed polarized light plus sensitive tint. Original at 200X.

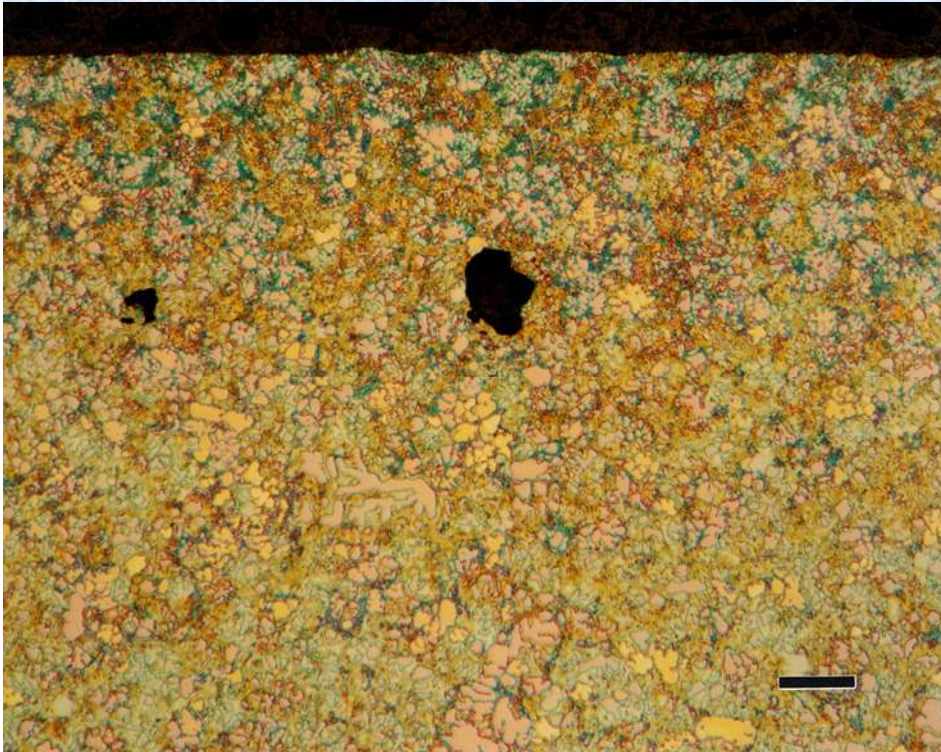


As-cast 357-T6 aluminum (Al – 7.0% Si – 0.5% Mg) etched with aqueous 0.5% HF revealing primary alpha dendrites and an alpha-Si eutectic. Magnification bar is 20 μm long.

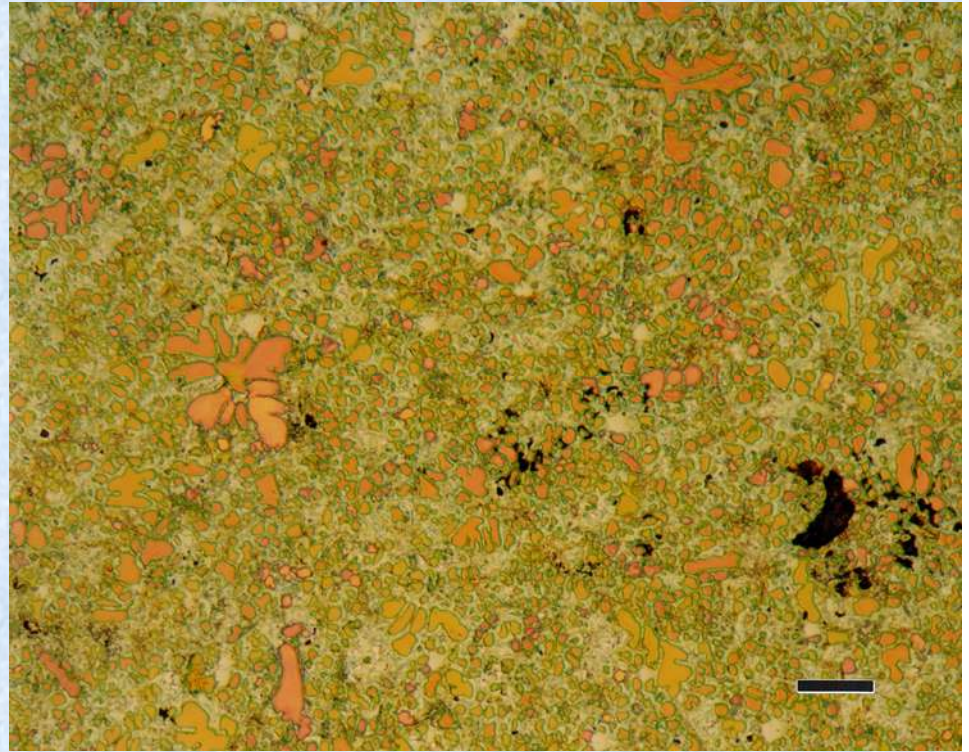


As-cast Al – 5% Si – 1.2% Cu – 1% Mg tint etched with Weck's reagent. The magnification bar is 50 μm long.

Surface



Interior



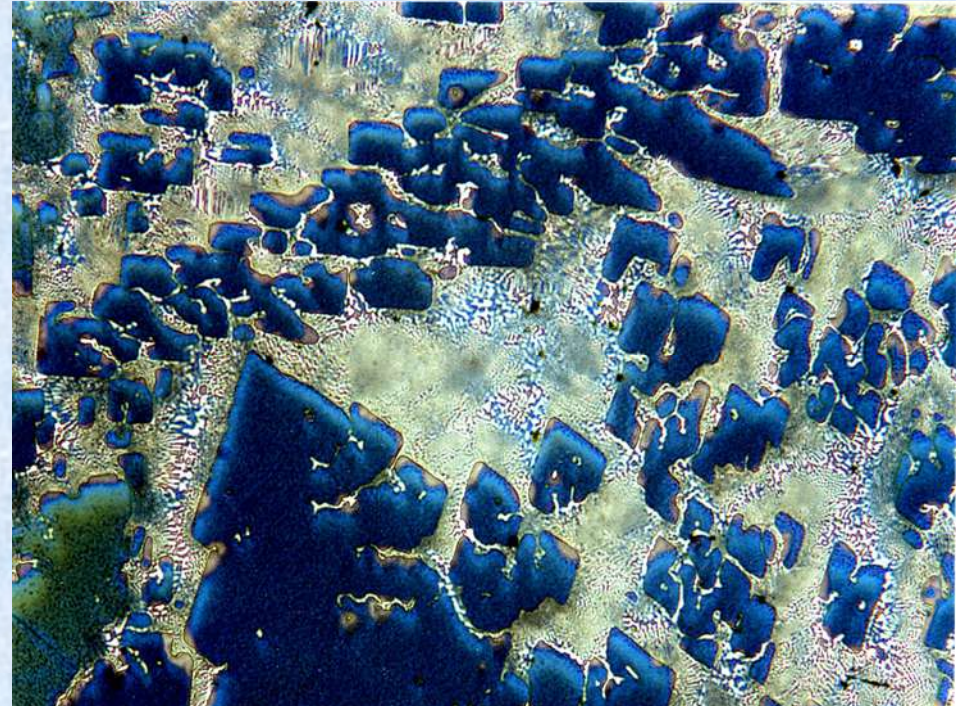
Microstructure of pressure-die cast A380 aluminum (Al – 8.5% Si – 3.5% Cu) etched with Weck's reagent and photographed in bright field illumination. Note that the silicon particles were colored by the reagent. The magnification bars are both 50 μm long.

As-Cast Al – Cu Alloys

Al – 33% Cu

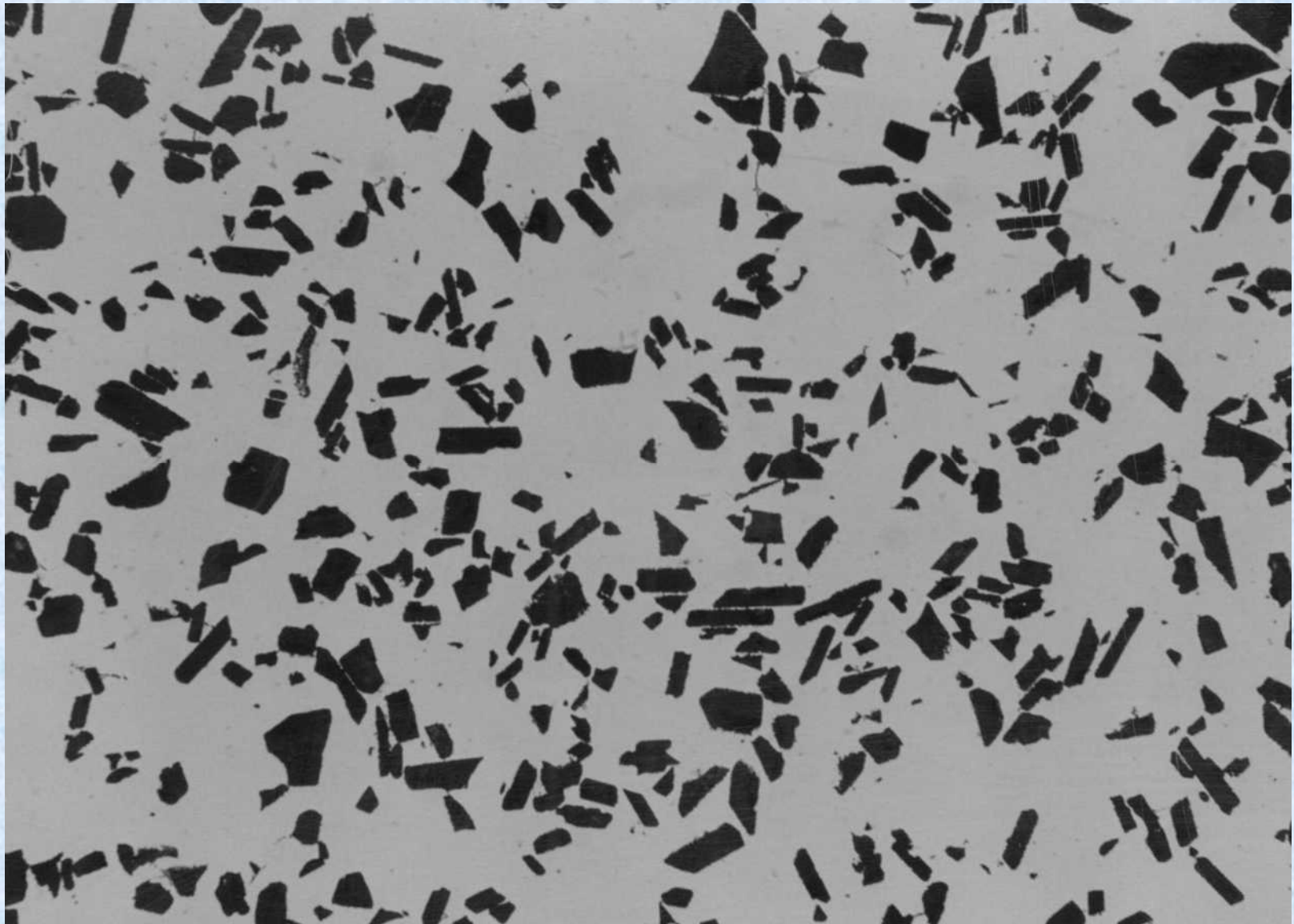


Al – 45% Cu

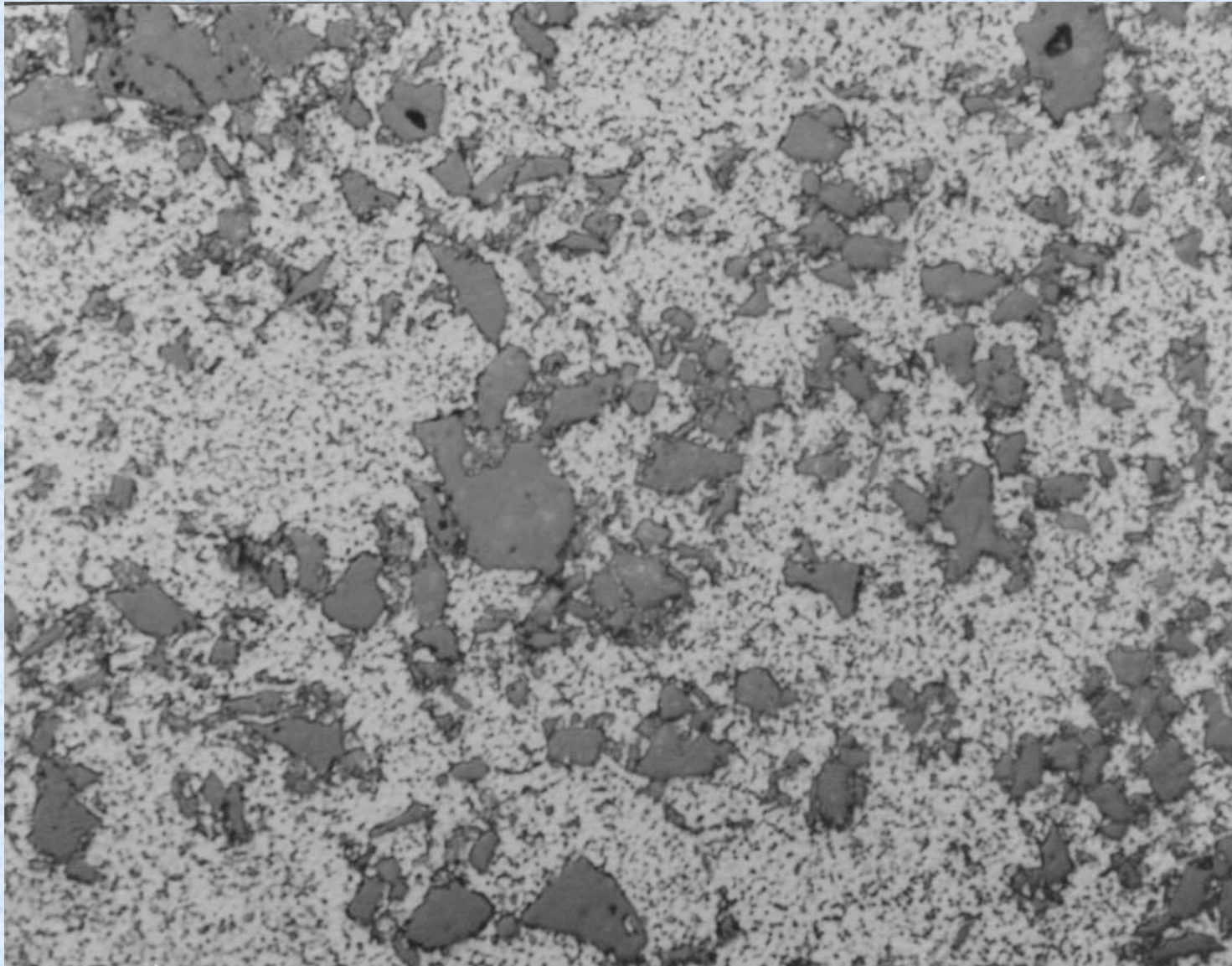


Eutectic in the Al-Cu system at 33% Cu is shown at left at 1000X. The AlCu₂ phase was colored red using 1 g ammonium molybdate, 6 g ammonium chloride and 200 mL water. Hypereutectic Al – 45% Cu is shown at right at 50X. The AlCu₂ was colored blue using 1 part 3g ammonium molybdate, 20 mL HNO₃, 20 mL water to 4 parts ethanol.

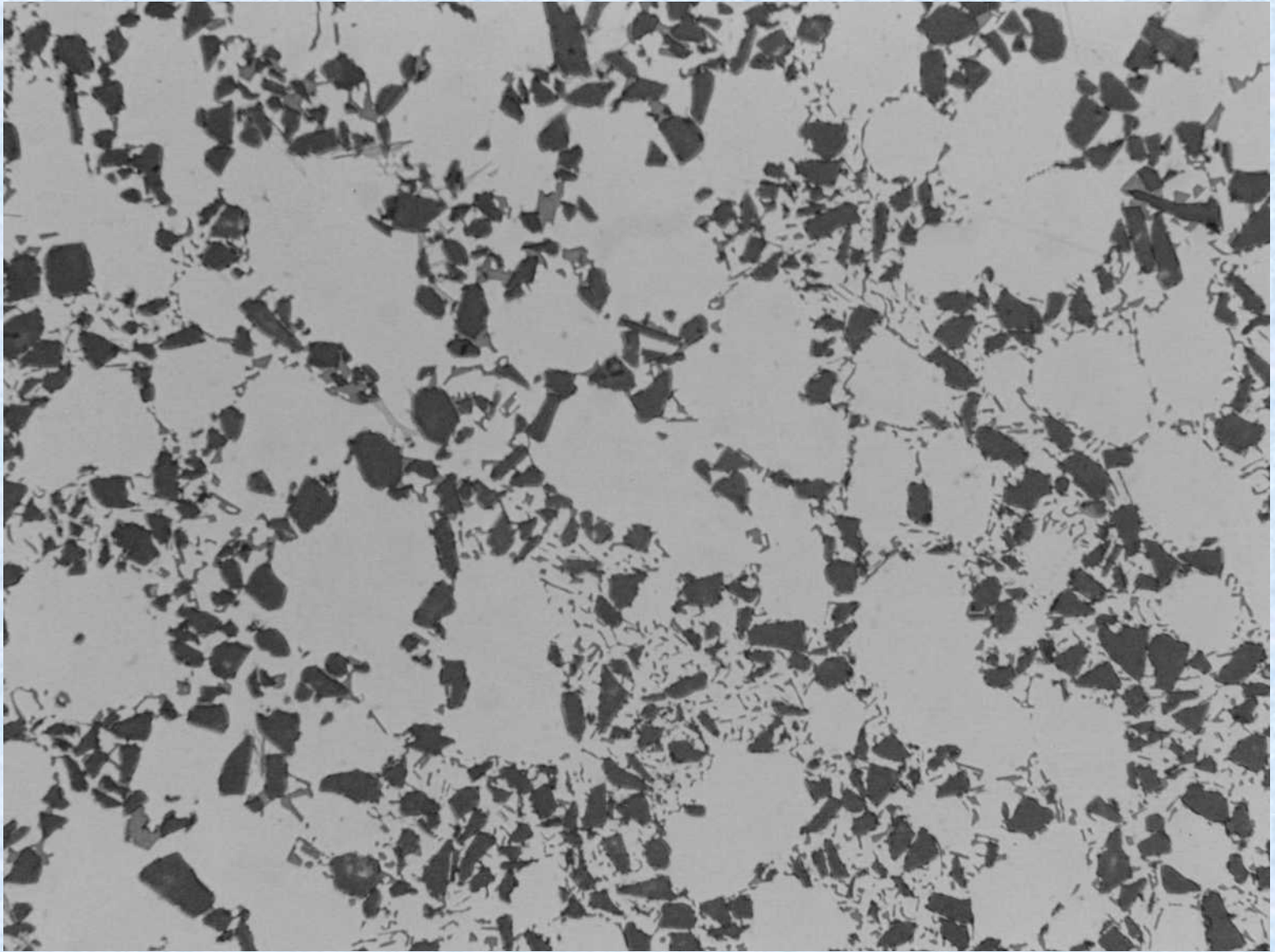
Composites



Composite of wrought 6061 aluminum and 22.5 wt. % alumina (Al_2O_3). As polished. Original at 200X.

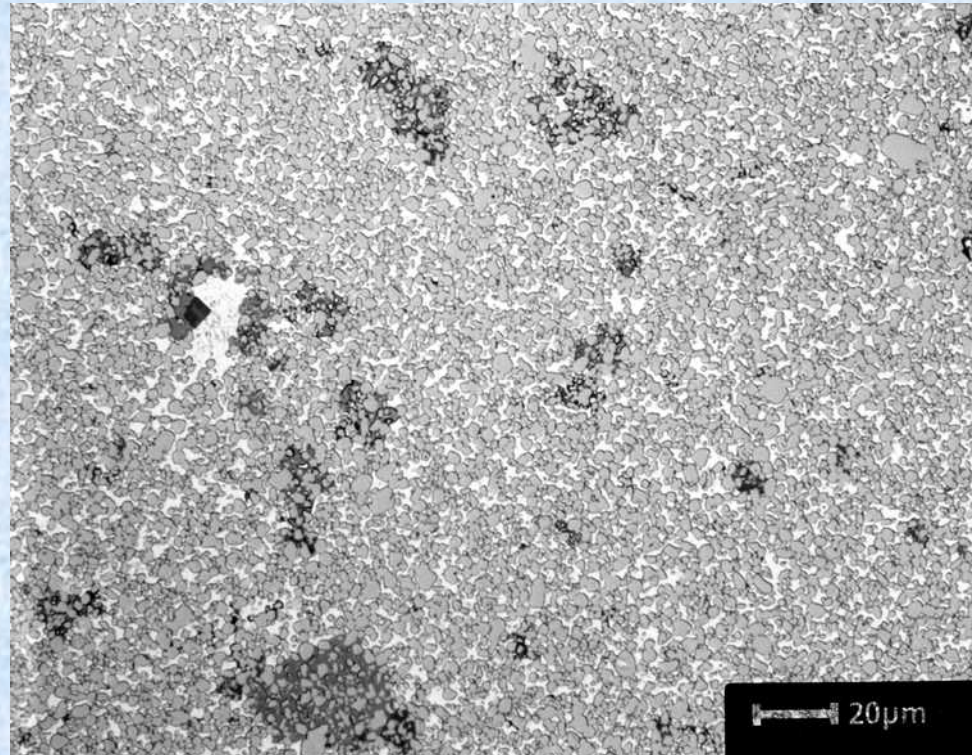


Composite of wrought 2124 aluminum and 20 wt. % SiC. As polished. Original at 1000X.



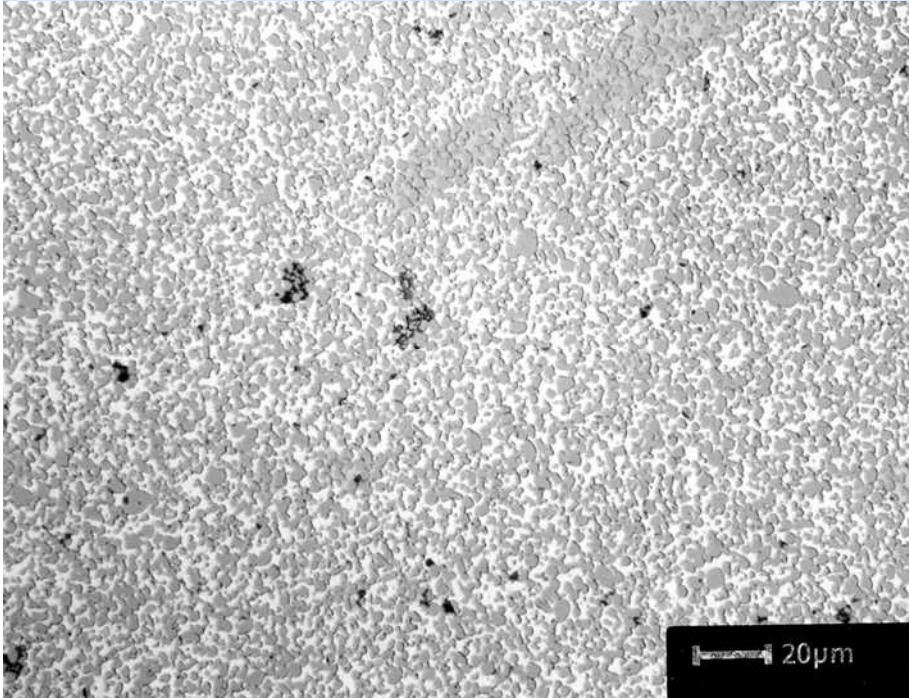
Composite of A356 as-cast aluminum and 21.2 wt. % SiC. As-polished. Original at 200X.

2024 Al – 55% TiC Composite – As Fabricated

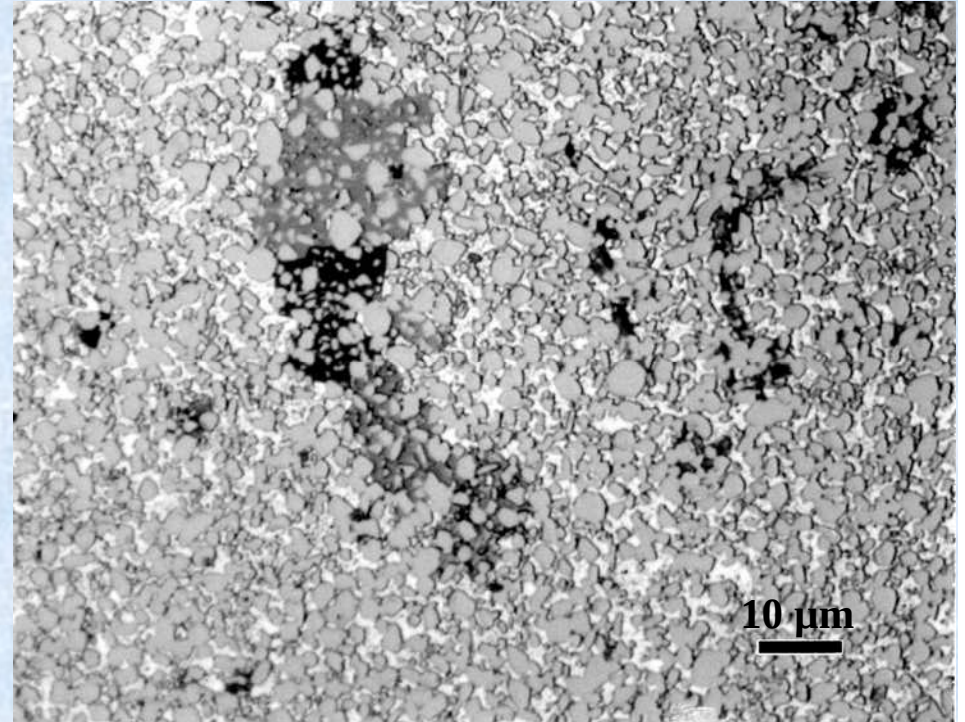


Segregation in the composite viewed after etching with Keller's reagent.

2024 Al – 55% TiC Composite – Solution Annealed and Aged



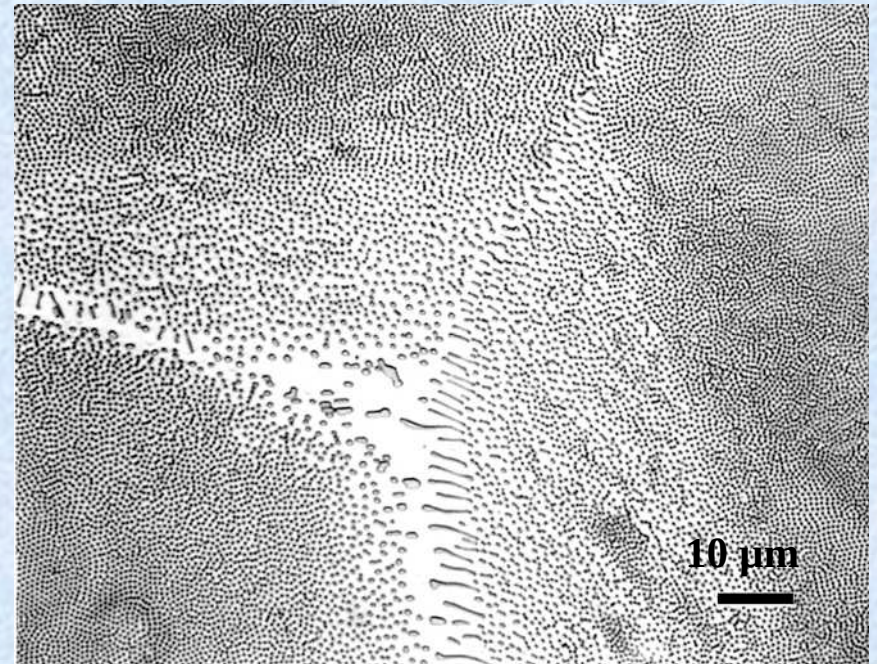
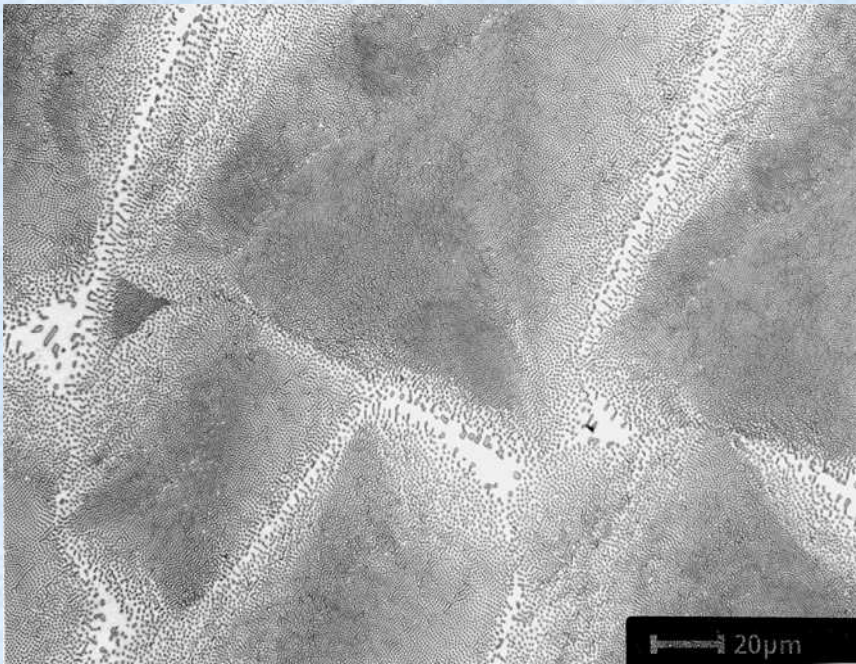
As Polished



Keller's Reagent

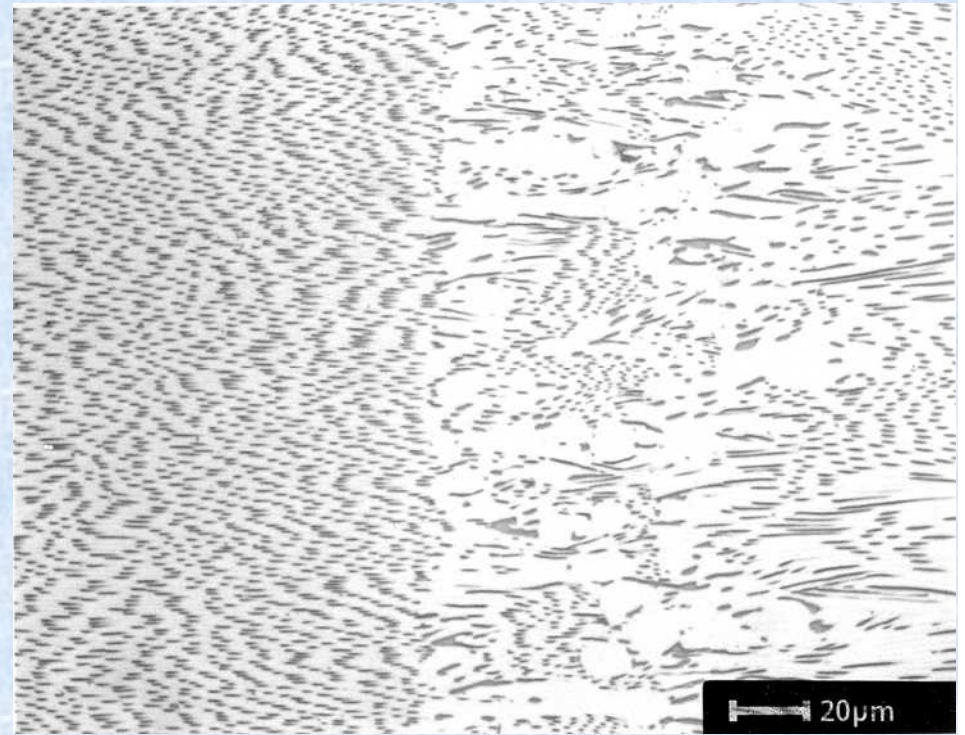
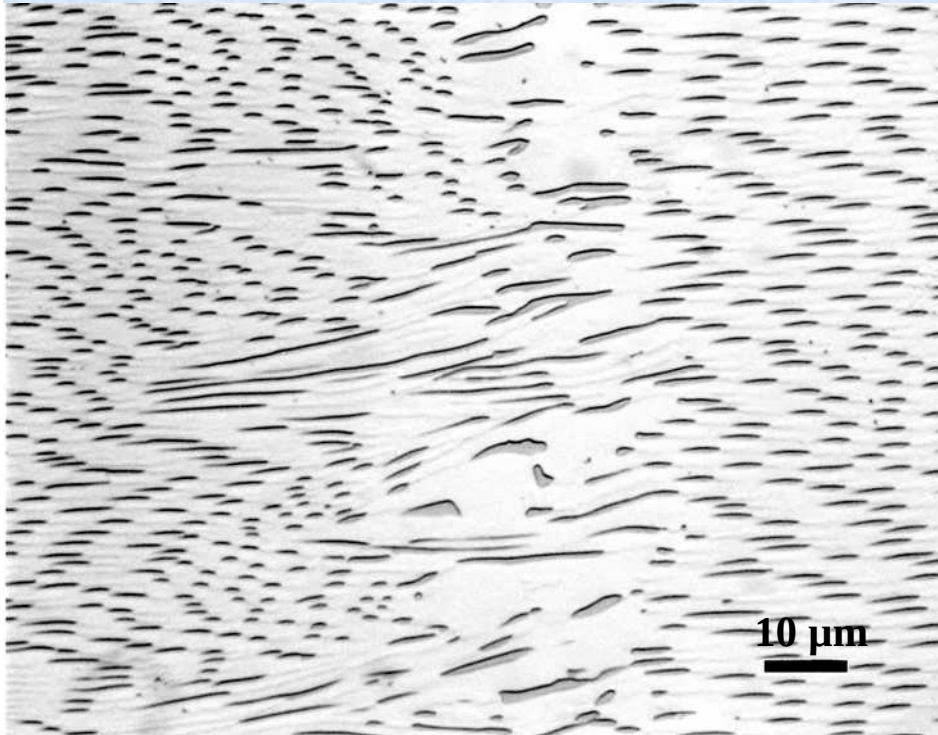
Views of the heterogeneity in the composite

Al – Al₃Ni Directionally Solidified Eutectic



α -Al – Al₃Ni DS eutectic, perpendicular to growth direction, aqueous 0.5% HF.

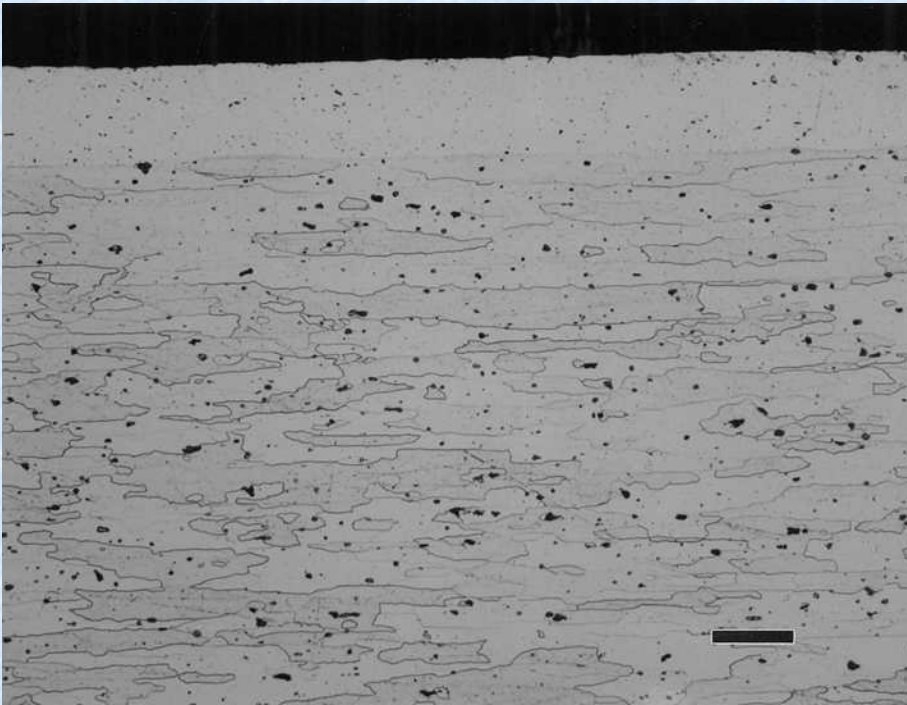
Al – Al₃Ni Directionally Solidified Eutectic



Two views of the DS eutectic structure on a plane parallel to the growth direction, aqueous 0.5% HF etch

Coated Specimens

Aluminum Clad 2024 Aluminum



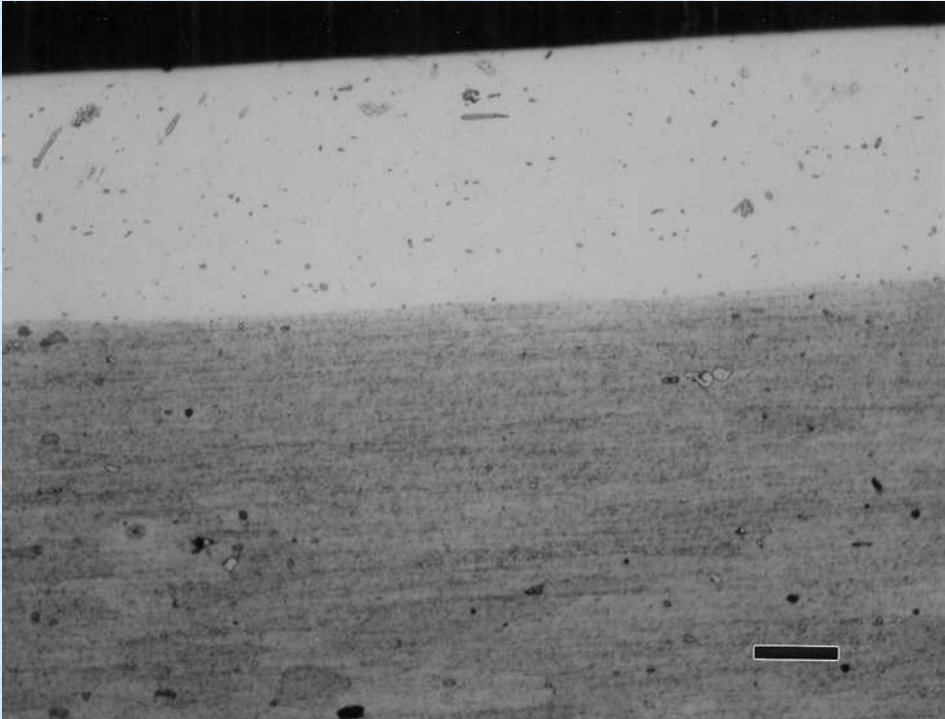
Bright Field



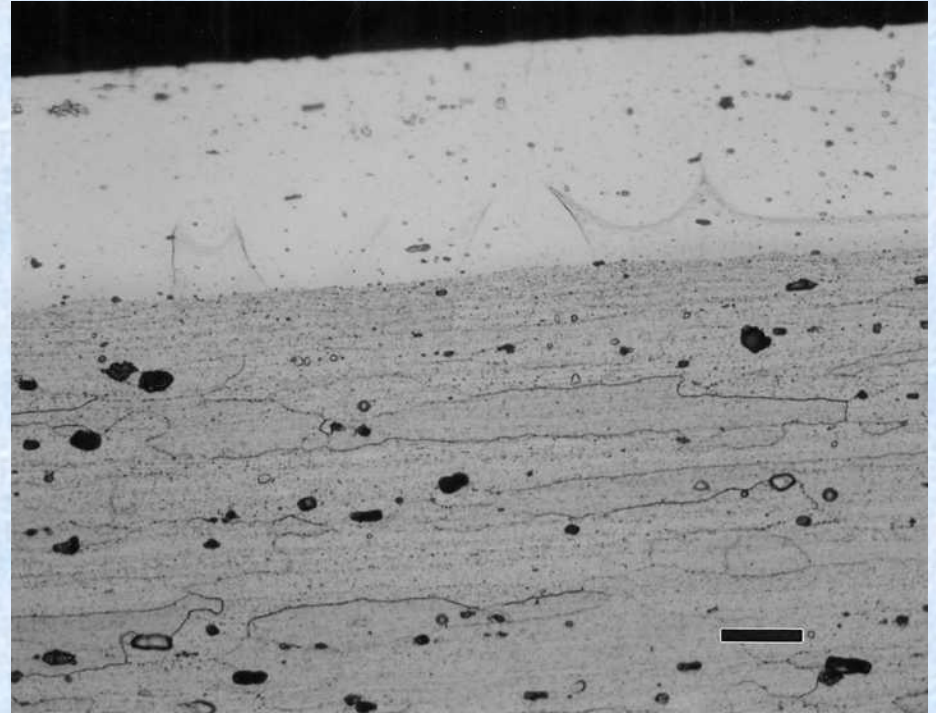
Nomarski DIC

Microstructure of Al-clad 2024 aluminum etched with Keller's reagent. The specimen was mounted in Epo-Thin epoxy resin. The magnification bars are both 50 μm long. The interface is not distinct in bright field but is more clearly seen in DIC.

Aluminum Clad 2024 Aluminum



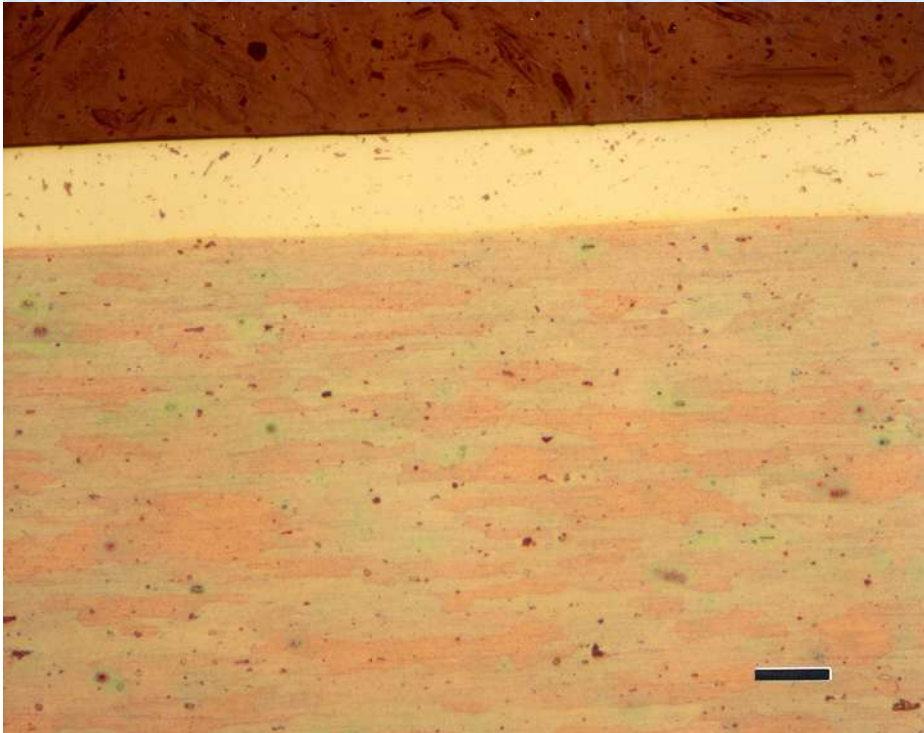
Weck's Reagent



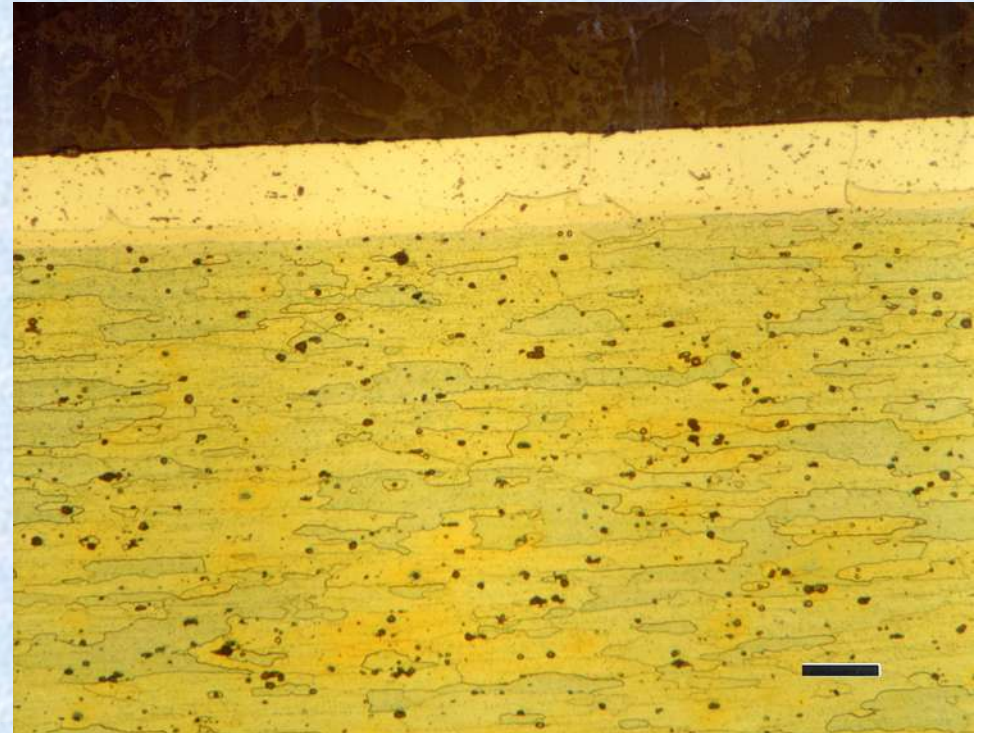
Keller's/Weck's Reagents

Microstructure of Al-clad 2024 aluminum etched with Weck's tint etch (left) and with Keller's reagent followed by Weck's (right). Weck's reagent reveals the interface much better than standard reagents. Keller's reveals the grain structure. The magnification bars are both 20 μm long.

Aluminum Clad 2024 Aluminum



Weck's Reagent



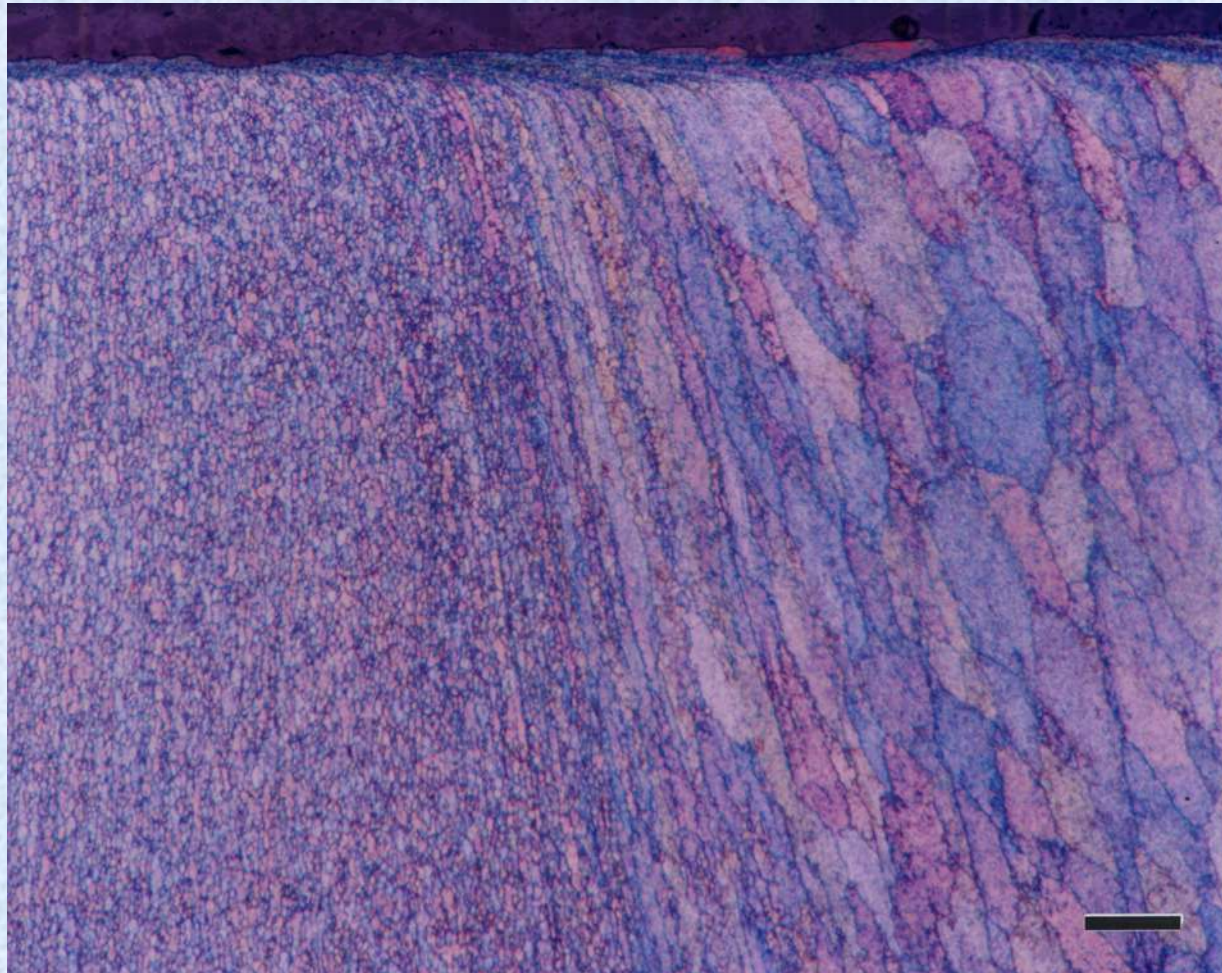
Keller's/Weck's Reagents

Microstructure of Al-clad 2024 aluminum etched with Weck's tint etch (left) and with Keller's reagent followed by Weck's (right). Weck's reagent reveals the interface much better than standard reagents. Keller's reveals the grain structure. The magnification bars are both 50 μm long.

Welded Alloys

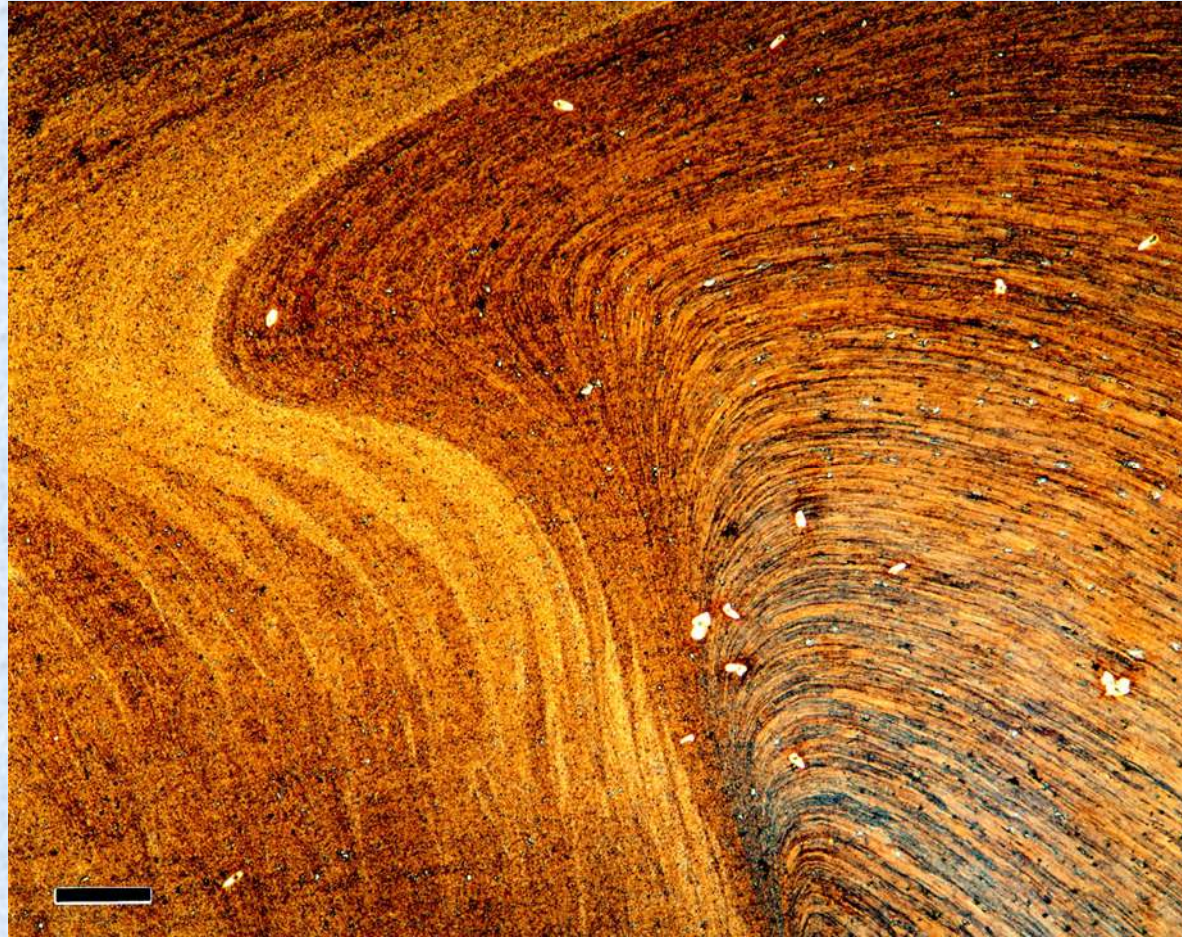
Weld

Base

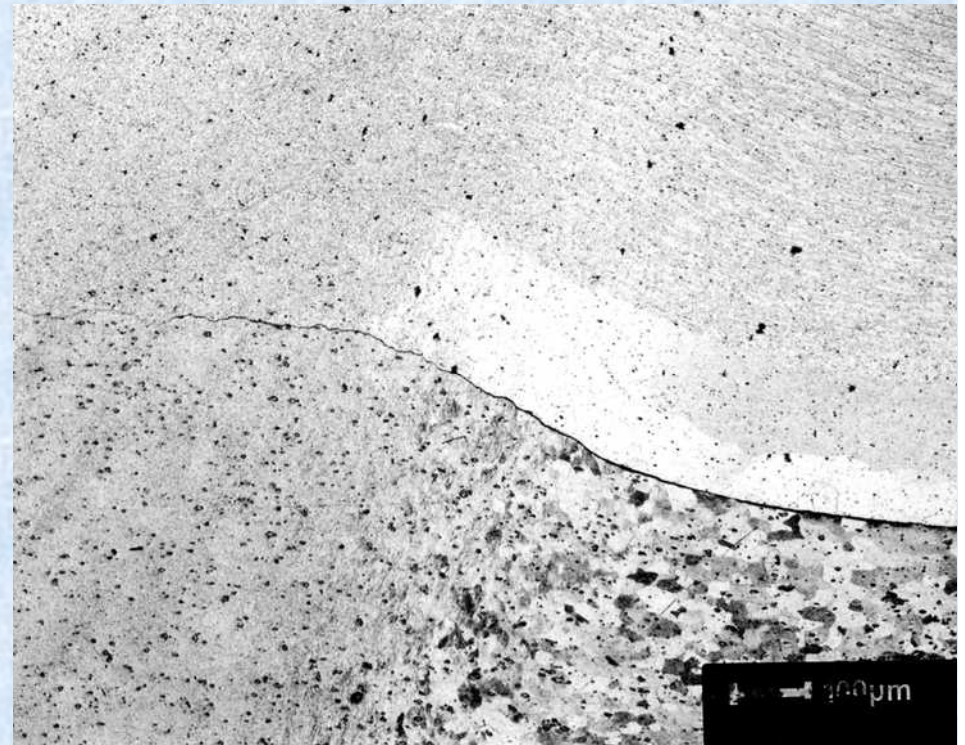


Microstructure of a friction stir weld in 2519 aluminum (Al – 5.8% Cu – 0.3% Mn – 0.3% Mg – 0.06% Ti – 0.1% V – 0.15% Zr) etched with Weck's reagent and viewed with polarized light plus sensitive tint. Original at 100X. The magnification bar is 100 μ m long.

Friction Stir Weld in 7075-T651



Weck's reagent used to reveal a friction stir weld in 7075-T651. The magnification bar is 200 μm long.



Microstructure of a friction stir weld between two wrought aluminum specimens revealed using Keller's reagent. Note that the B&W reagent does not reveal the microstructure as well as the color etchant.

Weld Nugget

HAZ

Base

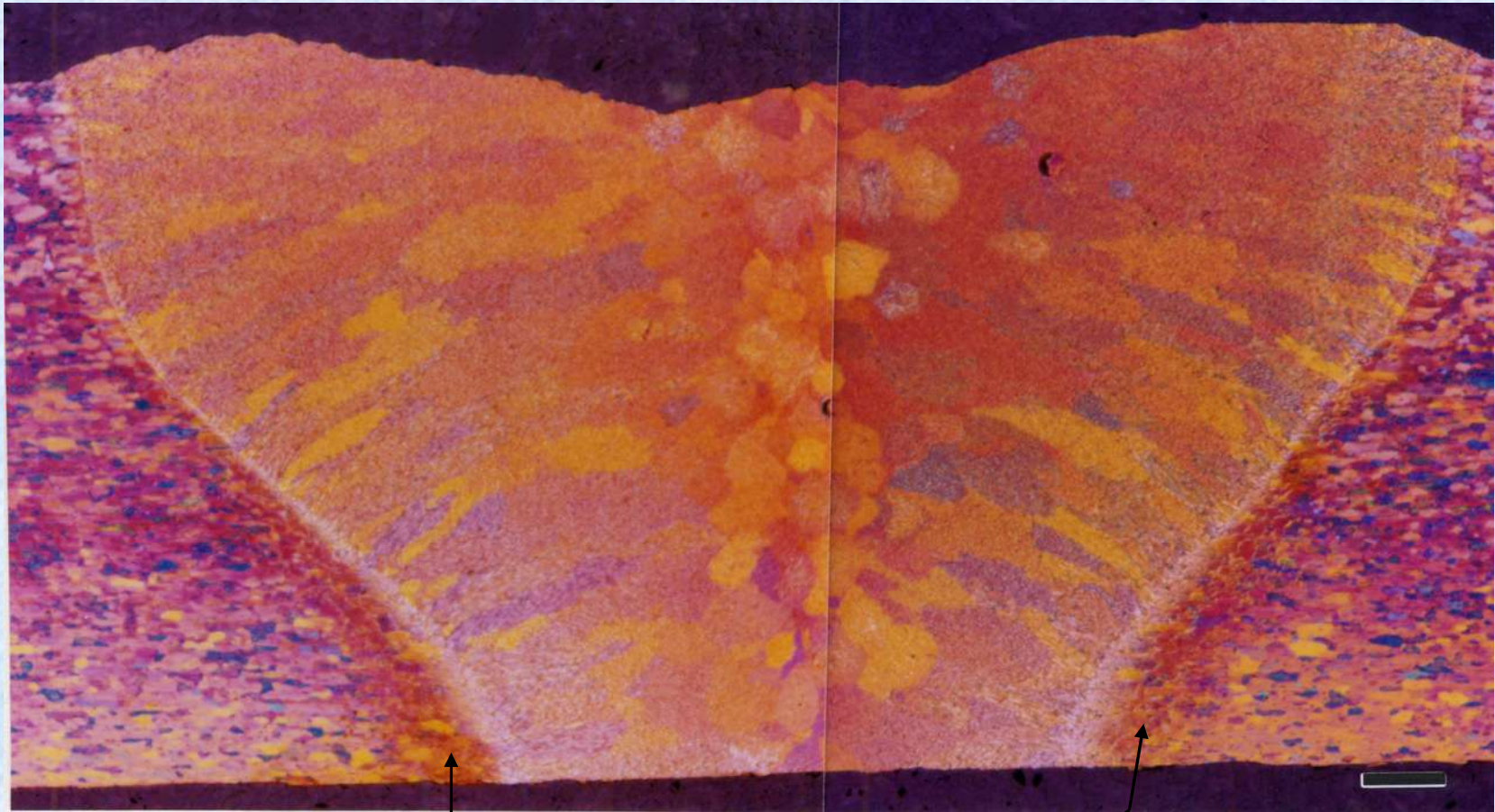


Microstructure of a laser weld in 5052 aluminum (Al – 2.5% Mg – 0.25% Cr) etched with Weck's reagent and viewed with polarized light plus sensitive tint. Original at 50X. The magnification bar is 200 μ m long.

The white arrow points to an undercut where the weld is recessed below the sheet surface. There is a globular inclusion at the base of the weld nugget.

Weld Nugget

Base



Heat Affected Zones

Microstructure of a laser weld in 6061 aluminum (Al – 0.6% Si – 0.3% Cu – 1% Mg – 0.2% Cr) etched with Weck's reagent and viewed with polarized light plus sensitive tint. Original at 50X. The magnification bar is 200 μm long.